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Space Administration

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RELATIVE RESISTANCE TO IGNITION OF SELECTED
TURBOPUMP MATERIALS IN HIGH-PRESSURE,
HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS,
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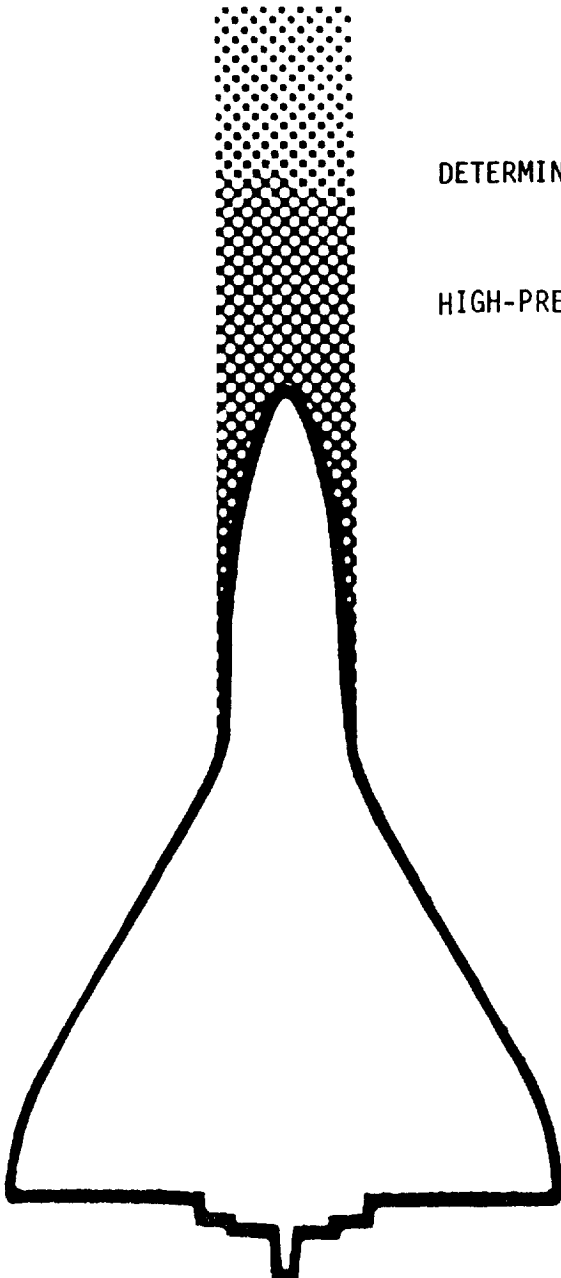
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TEST REPORT

VOLUME IV

DETERMINATION OF THE RELATIVE RESISTANCE TO IGNITION
OF SELECTED TURBOPUMP MATERIALS IN
HIGH-PRESSURE, HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS



Lyndon B. Johnson Space Center
White Sands Test Facility
Post Office Drawer MM
Las Cruces, New Mexico 88004
AC 505 524-5011

TEST REPORT
DETERMINATION OF THE RELATIVE RESISTANCE TO IGNITION
OF SELECTED TURBOPUMP MATERIALS IN
HIGH-PRESSURE, HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS

VOLUME IV

Issued By
National Aeronautics and Space Administration
Johnson Space Center
White Sands Test Facility
Laboratories Test Office

Prepared By: Joe M. Stoltzfus
Joe M. Stoltzfus, Lockheed-EMSCO

Prepared By: Frank J. Benz
Frank J. Benz/RF
NASA Laboratories Test Office

Approved By: Frank J. Benz for
David L. Pippen, Chief
NASA Laboratories Test Office

ABSTRACT

Advances in the design of the liquid oxygen, liquid hydrogen engines for the Space Transportation System call for the use of warm, high-pressure oxygen as the driving gas in the liquid oxygen turbopump. The NASA Lewis Research Center requested the NASA White Sands Test Facility (WSTF) to design a test program to determine the relative resistance to ignition of nine selected turbopump materials: Hastelloy X, Inconel 600, Invar 36, Monel K-500, Monel 400, nickel 200, silicon carbide, stainless steel 316, and zirconium copper. The materials were subjected to particle impact and to frictional heating in high-pressure oxygen.

In the particle impact tests, nickel 200, Monel 400, and silicon carbide were the most resistant to ignition; Monel K-500 and zirconium copper were slightly less resistant to ignition; and Hastelloy X, Invar 36, and stainless steel 316 were the least resistant to ignition. Inconel 600 was not tested.

In frictional heating tests of pairs of like materials, the ranking was generally upheld, with the materials ranked in order of decreasing resistance to ignition as follows: nickel 200, Inconel 600, Monel 400, Monel K-500, Hastelloy X, Invar 36, and stainless steel 316. Pairs of silicon carbide and zirconium copper failed mechanically at modest contact pressures and did not ignite.

In tests where pairs of different materials were rubbed together, the material rated less resistant to ignition in previous tests appeared to control the resistance to ignition of the pair.

Tests designed to determine the effects of oxygen pressure on the results of frictional heating appeared to indicate that the greater heat rates per unit area required to ignite metals at high pressures resulted from increased convective heat losses from the test samples.

PREFACE

This interim report addresses the test series that resulted from three test plans written at the NASA White Sands Test Facility in response to a request from the NASA Lewis Research Center to determine the relative compatibility of selected turbopump materials in gaseous oxygen. The first test plan, Determination of the Ignition Sensitivity of Selected Turbopump Metals in High Pressure, High Temperature, Oxygen Environments (TP-WSTF-324), proposed tests in which eight materials were impacted with particles in hot, high-pressure oxygen and nine materials were heated frictionally in high-pressure oxygen. The second test plan, TP-WSTF-324 ADDI, proposed tests in which pairs of different materials were rubbed together in high-pressure oxygen to induce frictional heating. The third test plan, Evaluation of Pressure Effects in the WSTF Friction Rubbing Test System (TP-WSTF-356), proposed tests to determine the effects of the test gas pressure on the results of frictional heating tests. Testing proposed in the first and third test plans has been completed, and six of the eight tests proposed in the second test plan have been completed.

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APPENDIX F

Data From Frictional Heating Tests to Determine the Affects
of Oxygen Pressure on the Pv Product Required for Ignition

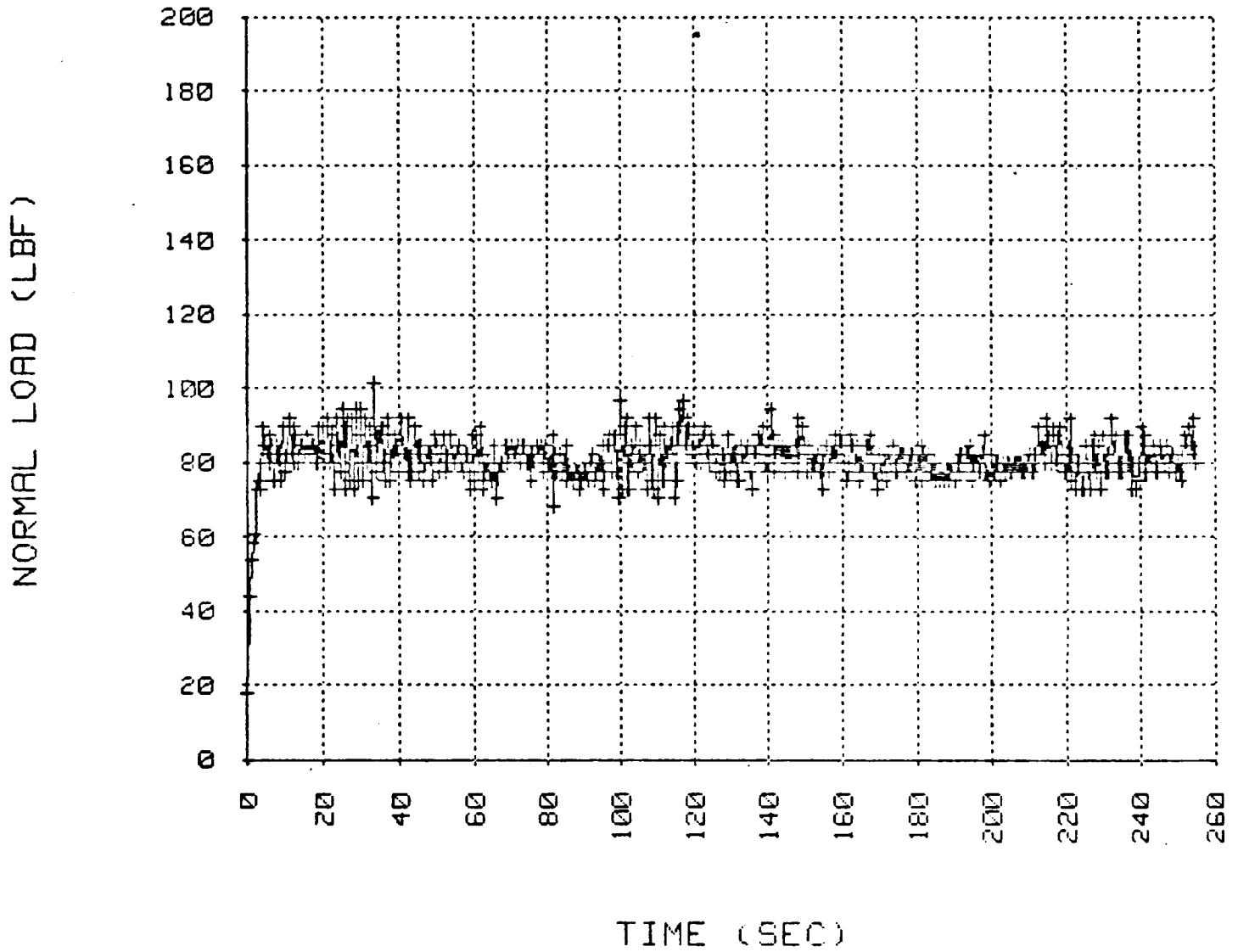
TEST NUMBER	TEST MATERIAL	TEST GAS	PRESSURE (PSIG)	PAGE
236	Mone1 K-500	GOX	Varied	F-1
237	Mone1 K-500	GOX	Varied	F-9
238	Mone1 K-500	GN ₂	100	F-17
242	Mone1 K-500	GOX	3000	F-25
244	Mone1 K-500	GN ₂	3000	F-32
245	Mone1 K-500	GOX	1000	F-38
246	Mone1 K-500	GOX	1000	F-45
247	Mone1 K-500	GOX	1000	F-49
216A	1015 Carbon Steel	GN ₂	100	F-53
218	1015 Carbon Steel	GN ₂	100	F-58
220	1015 Carbon Steel	GN ₂	100	F-63
222	1015 Carbon Steel	GN ₂	100	F-68
223	1015 Carbon Steel	GN ₂	100	F-73
224	1015 Carbon Steel	GN ₂	100	F-78
225	1015 Carbon Steel	GN ₂	100	F-83
226	1015 Carbon Steel	GN ₂	1000	F-88
229	1015 Carbon Steel	GN ₂	3000	F-93
230	1015 Carbon Steel	GN ₂	3000	F-98
231	1015 Carbon Steel	GN ₂	1000	F-103
212	1015 Carbon Steel	GOX	Ambient	F-108
213	1015 Carbon Steel	GOX	Ambient	F-113
214	1015 Carbon Steel	GOX	Ambient	F-118
209	1015 Carbon Steel	GOX	100	F-123
210	1015 Carbon Steel	GOX	100	F-128
211	1015 Carbon Steel	GOX	100	F-133
206	1015 Carbon Steel	GOX	500	F-138

APPENDIX F (CONTINUED)

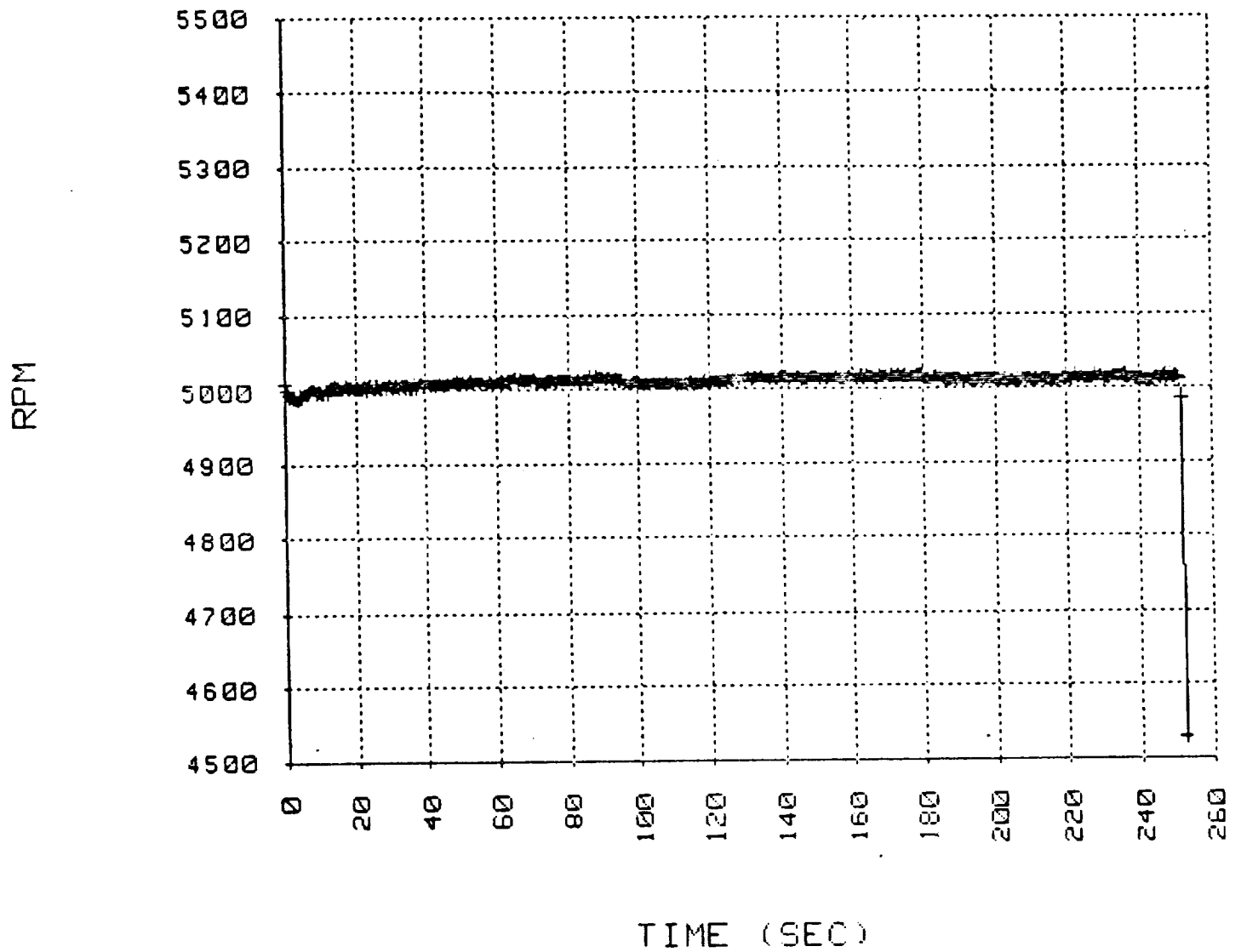
Data From Frictional Heating Tests to Determine the Affects
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207	1015 Carbon Steel	GOX	500	F-144
92	1015 Carbon Steel	GOX	1000	F-149
93	1015 Carbon Steel	GOX	1000	F-156
94	1015 Carbon Steel	GOX	1000	F-162
215	1015 Carbon Steel	GOX	3000	F-169
216	1015 Carbon Steel	GOX	3000	F-174

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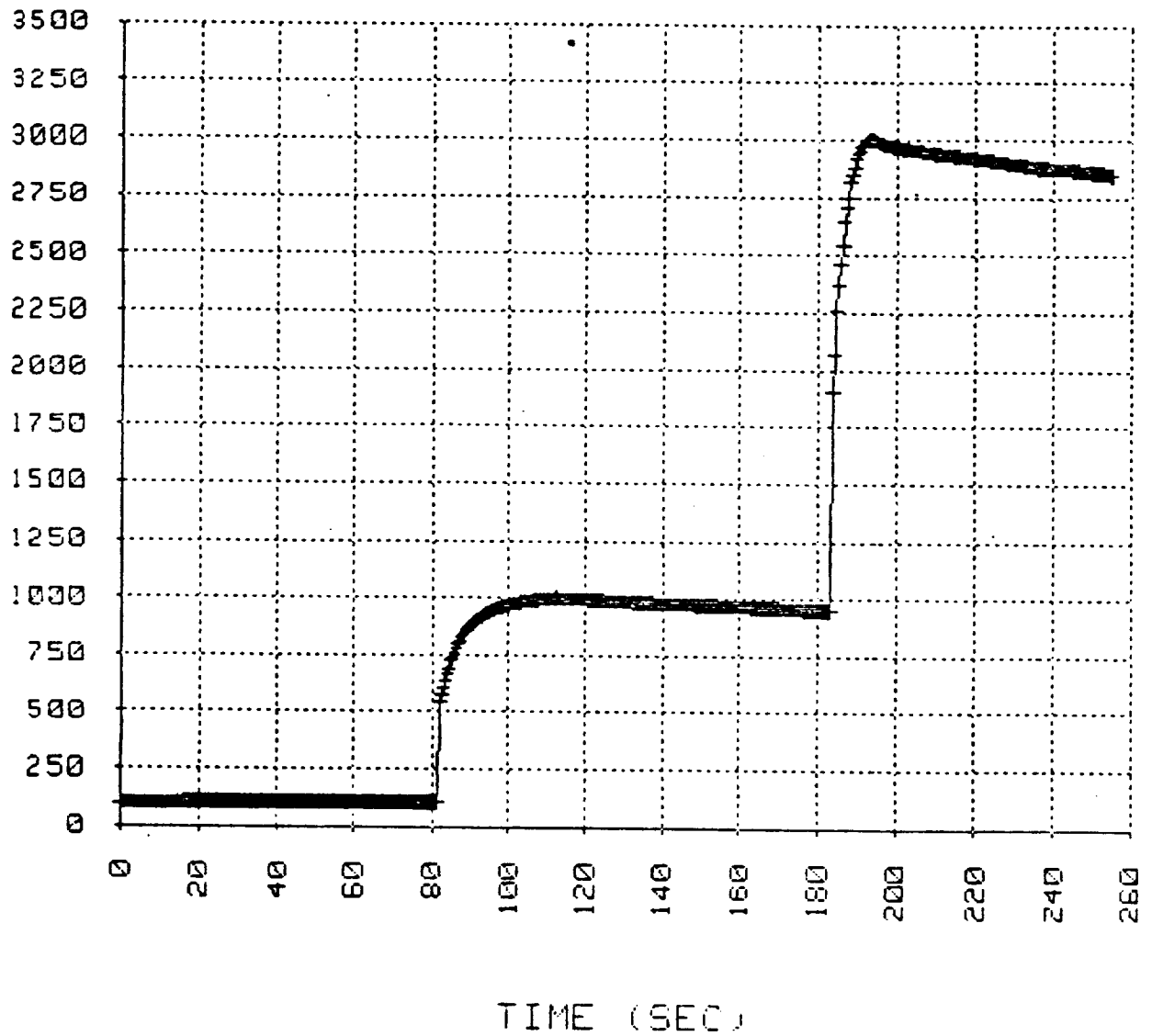
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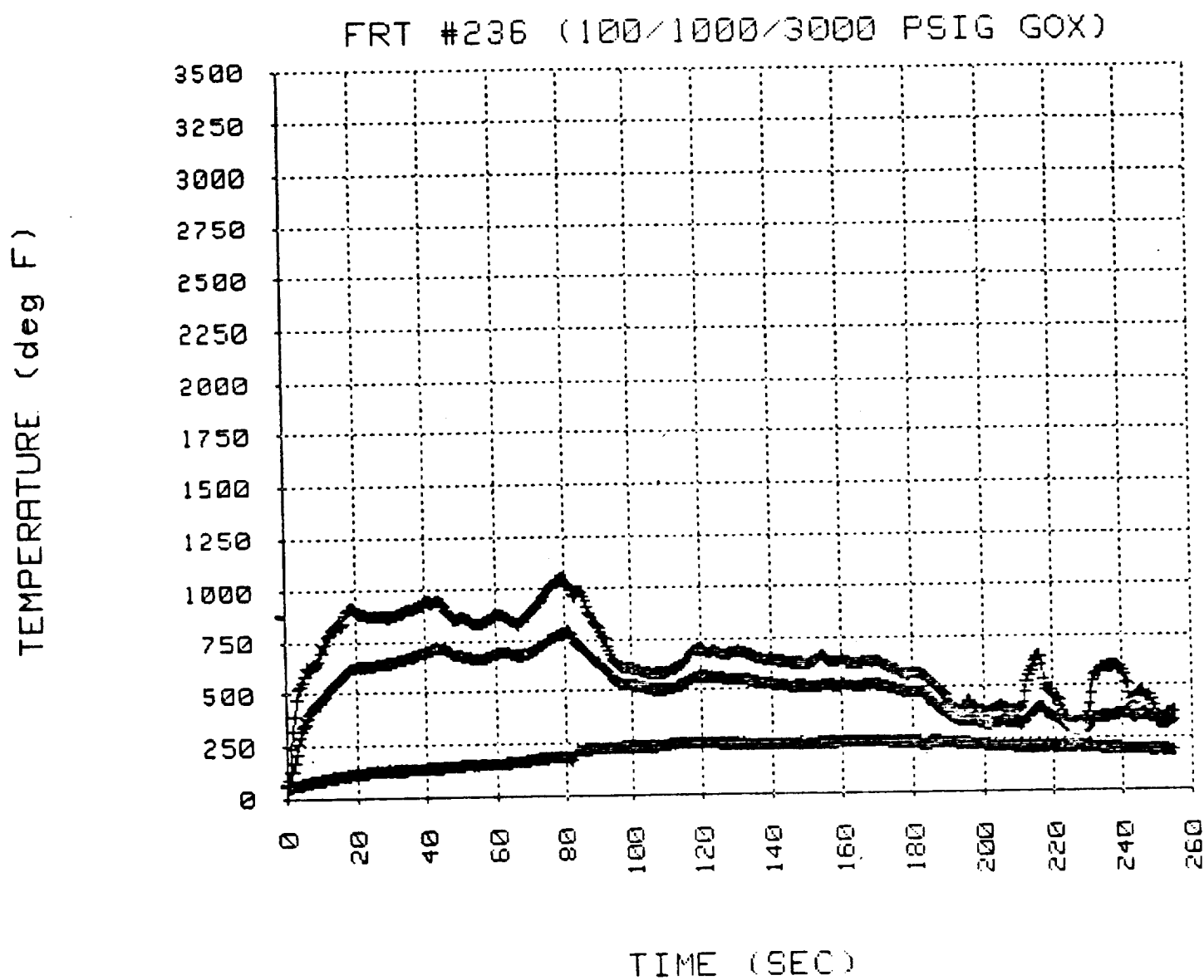


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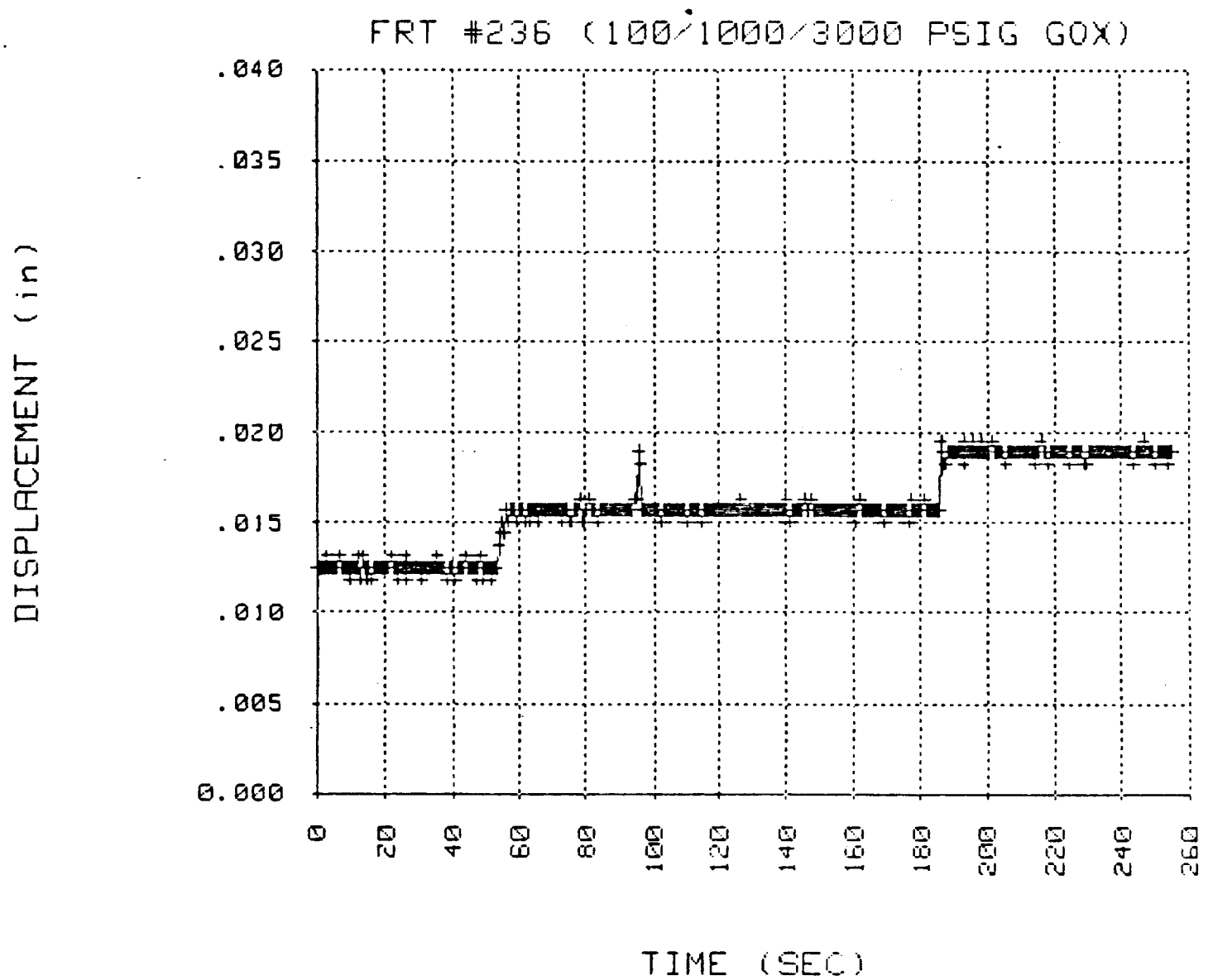
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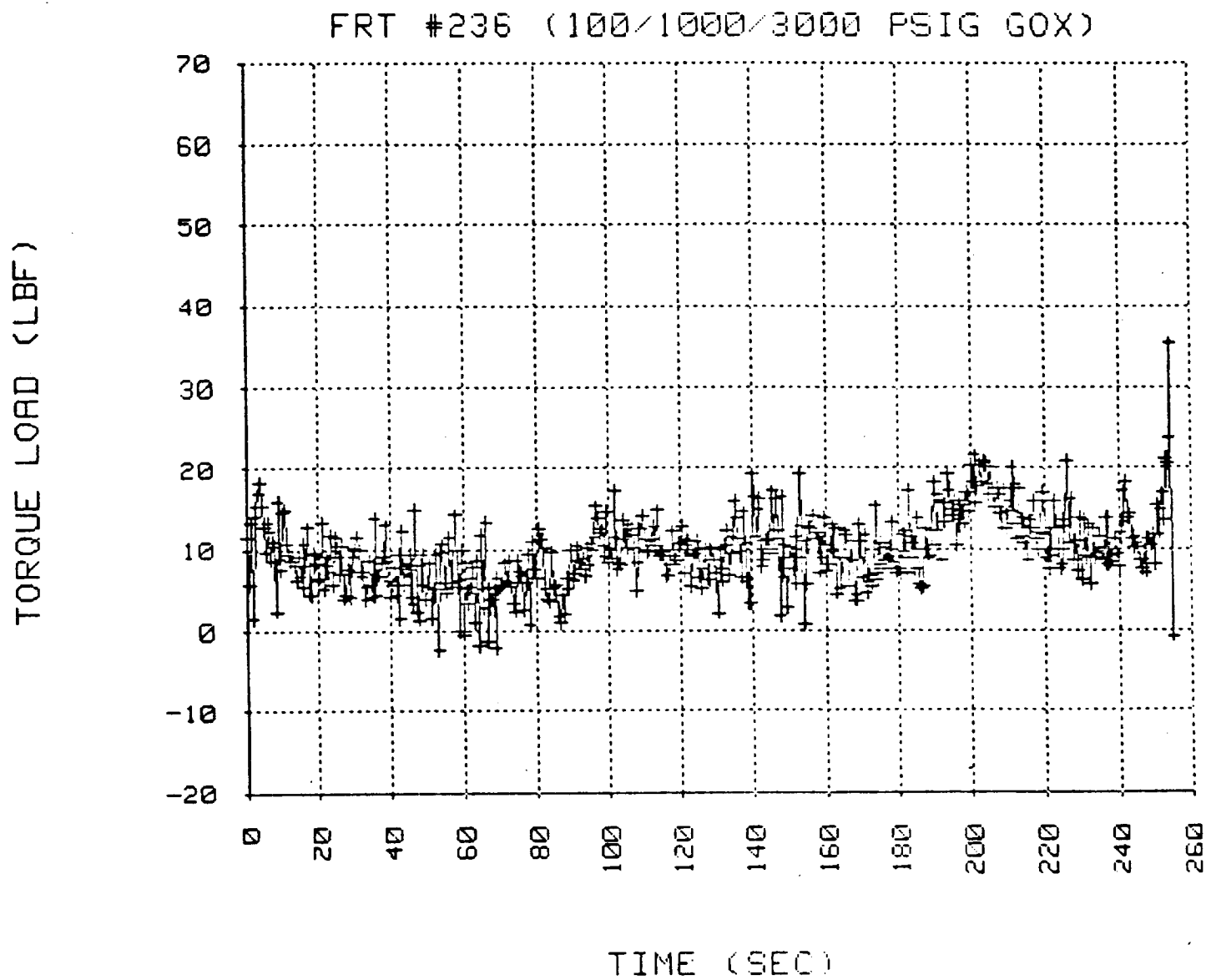




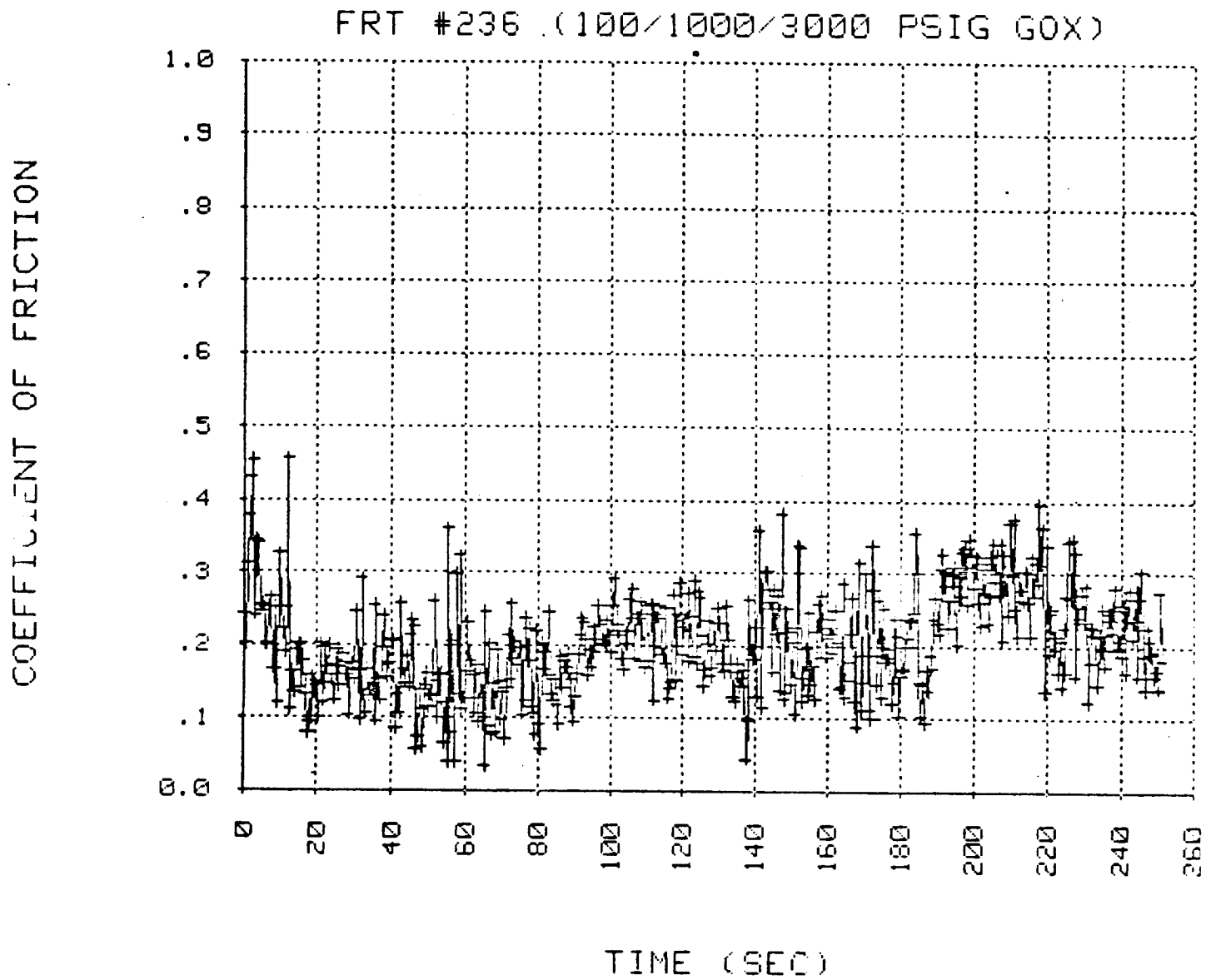
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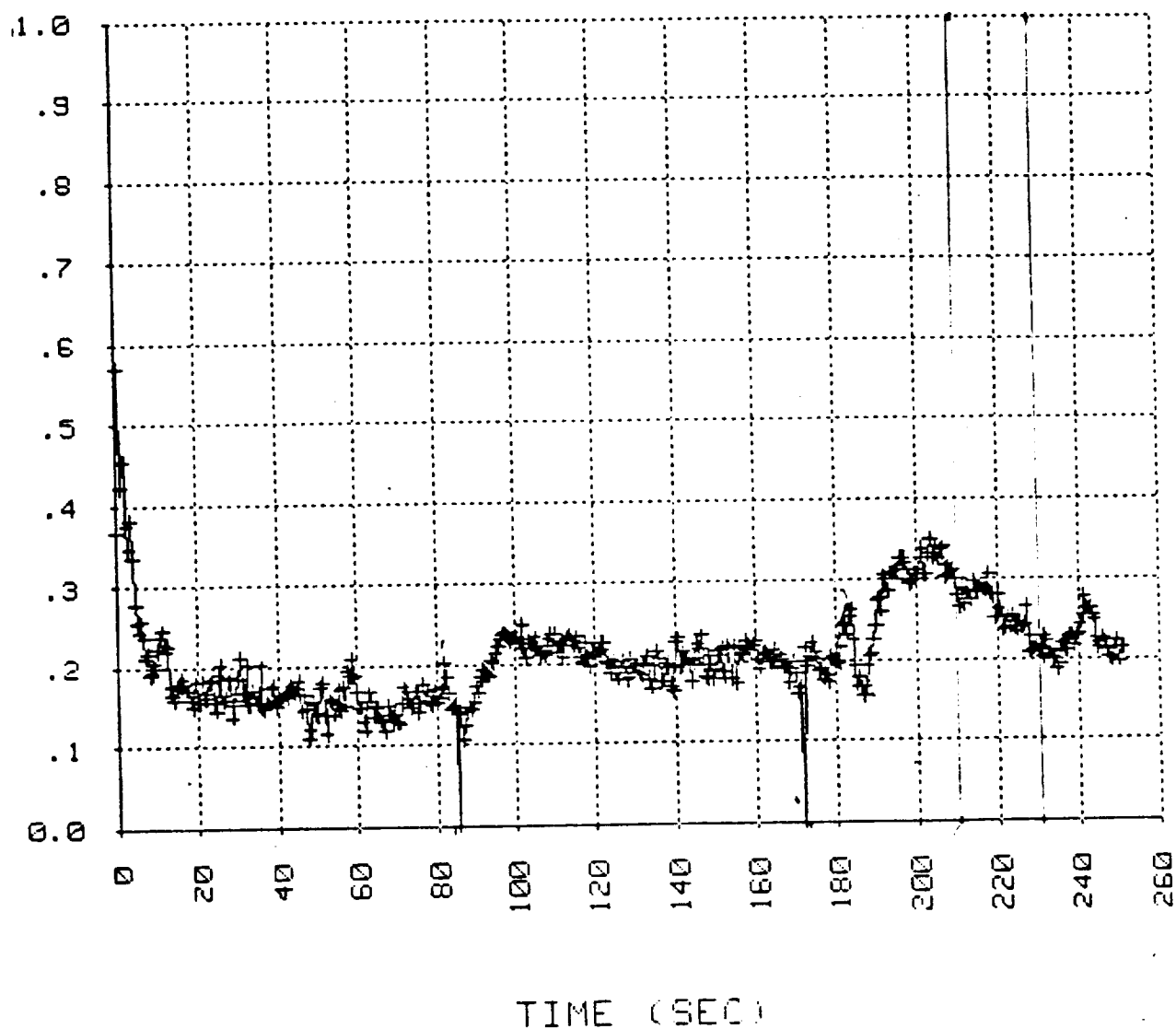


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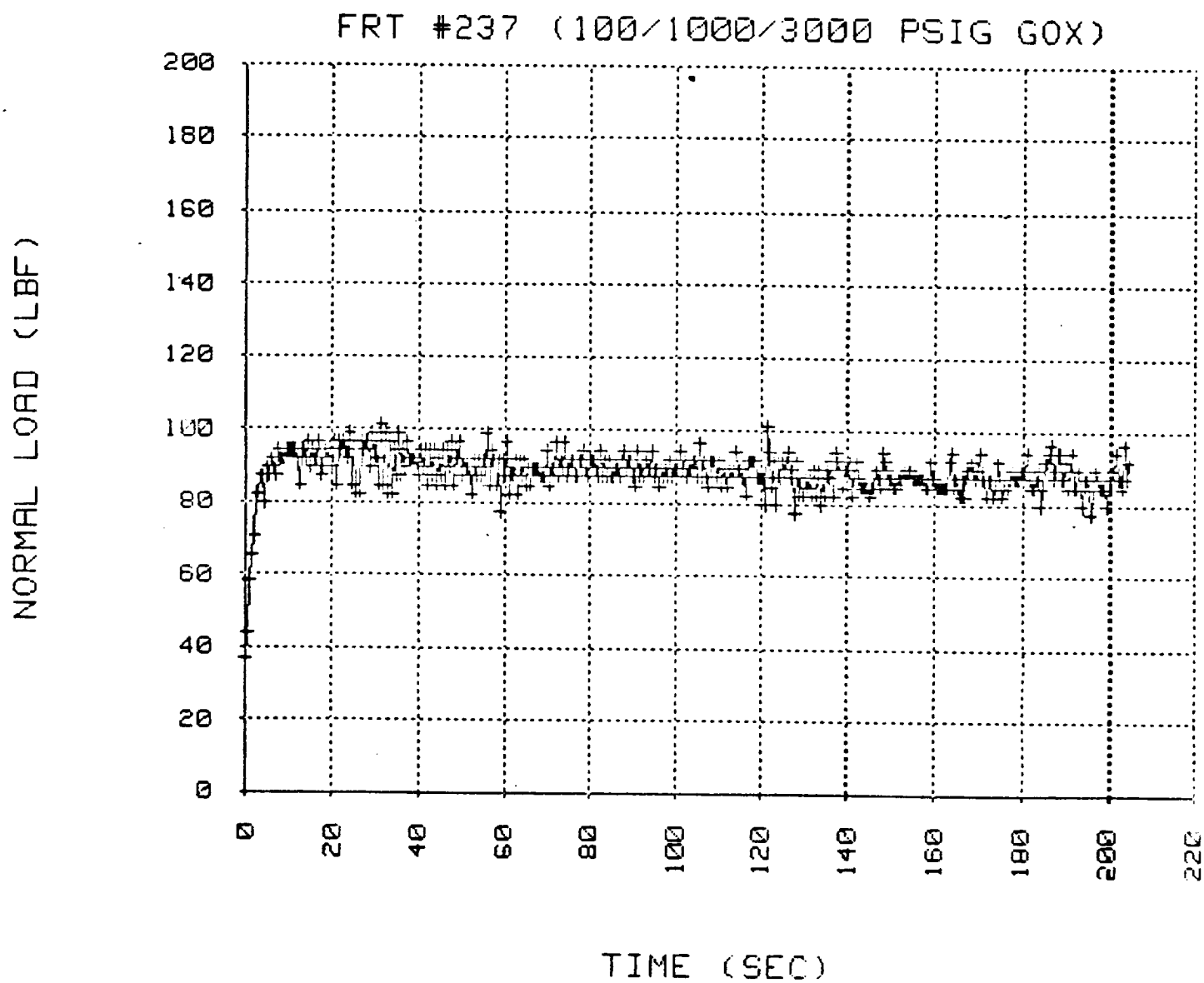


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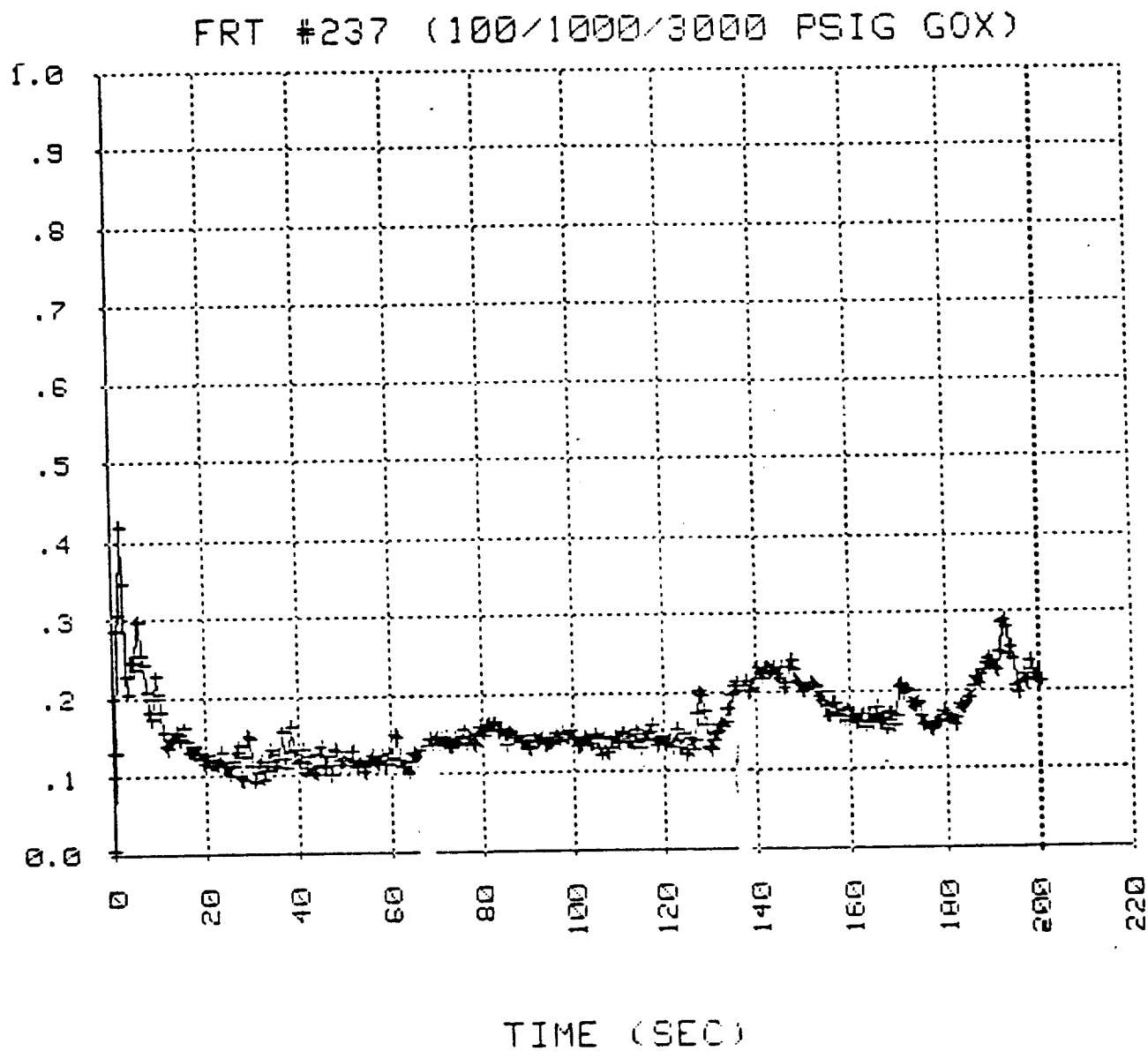
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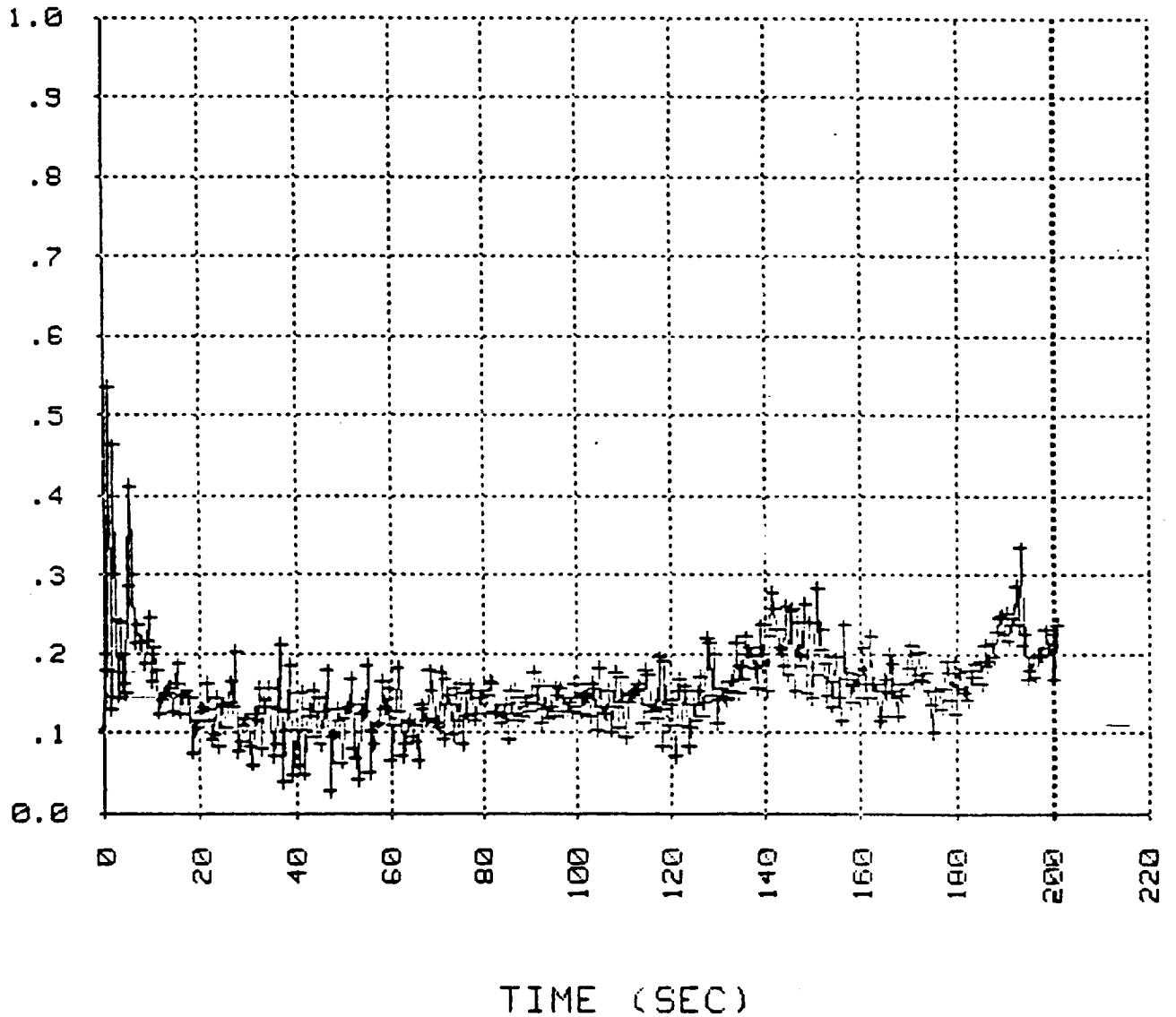
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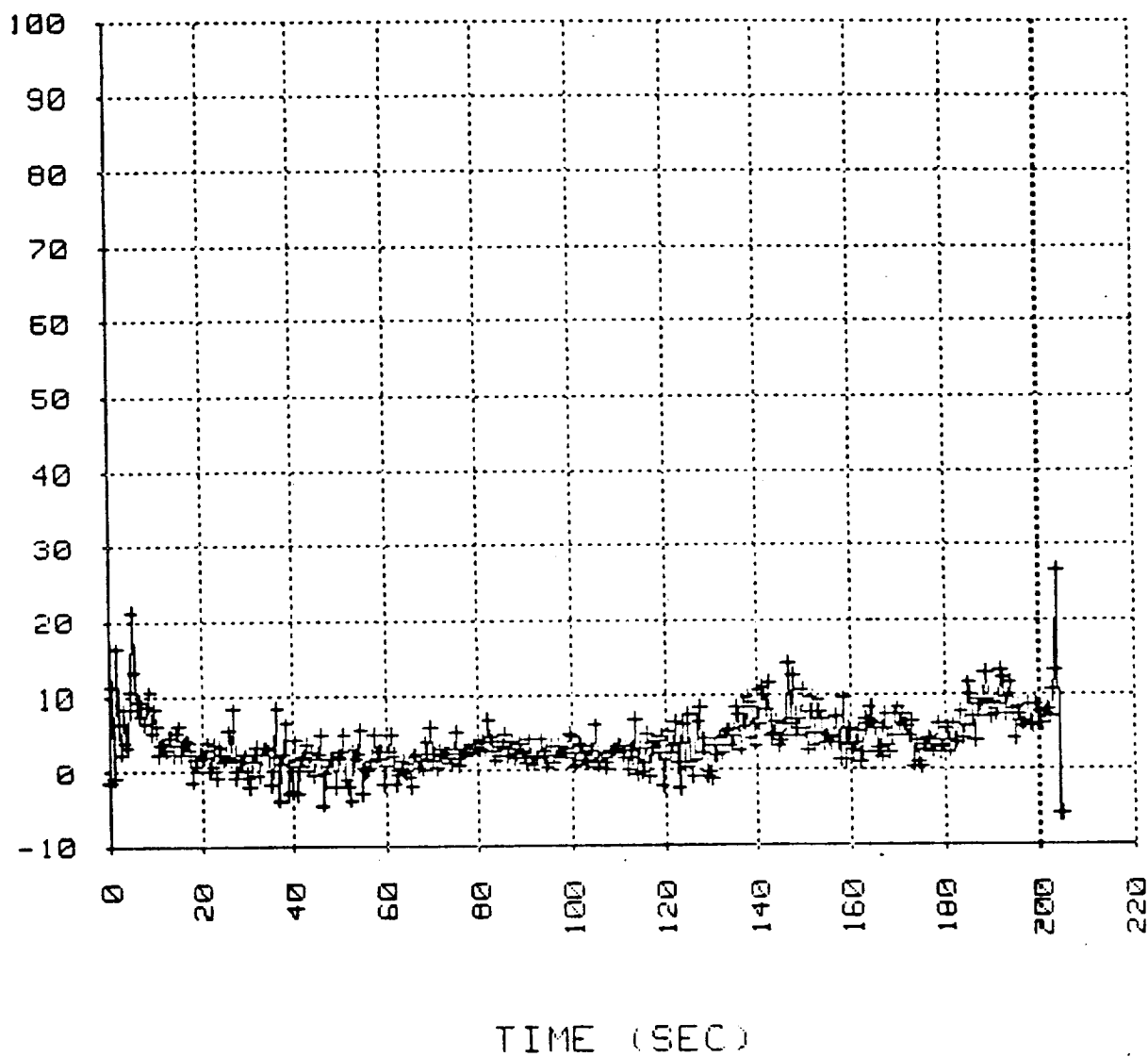
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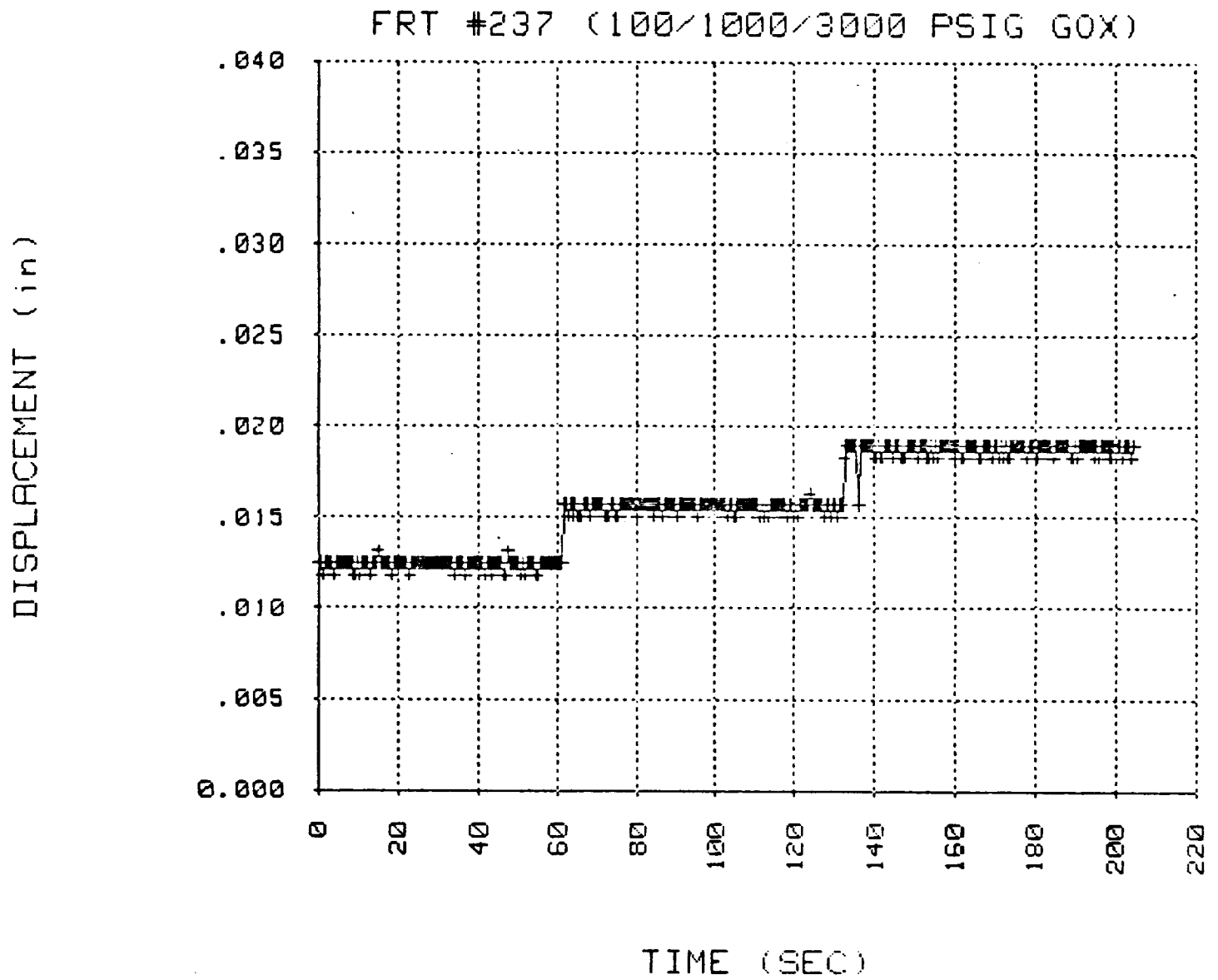


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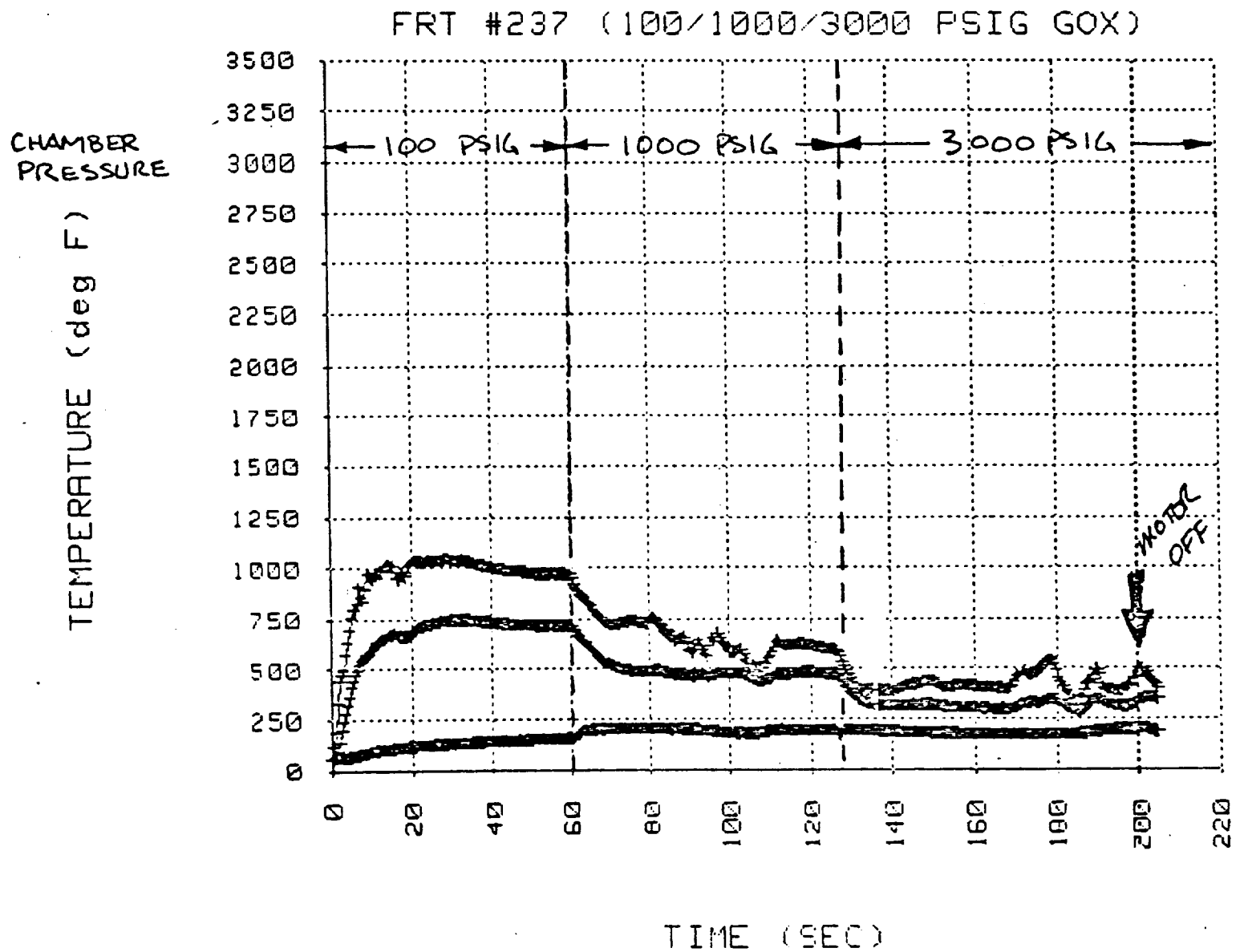
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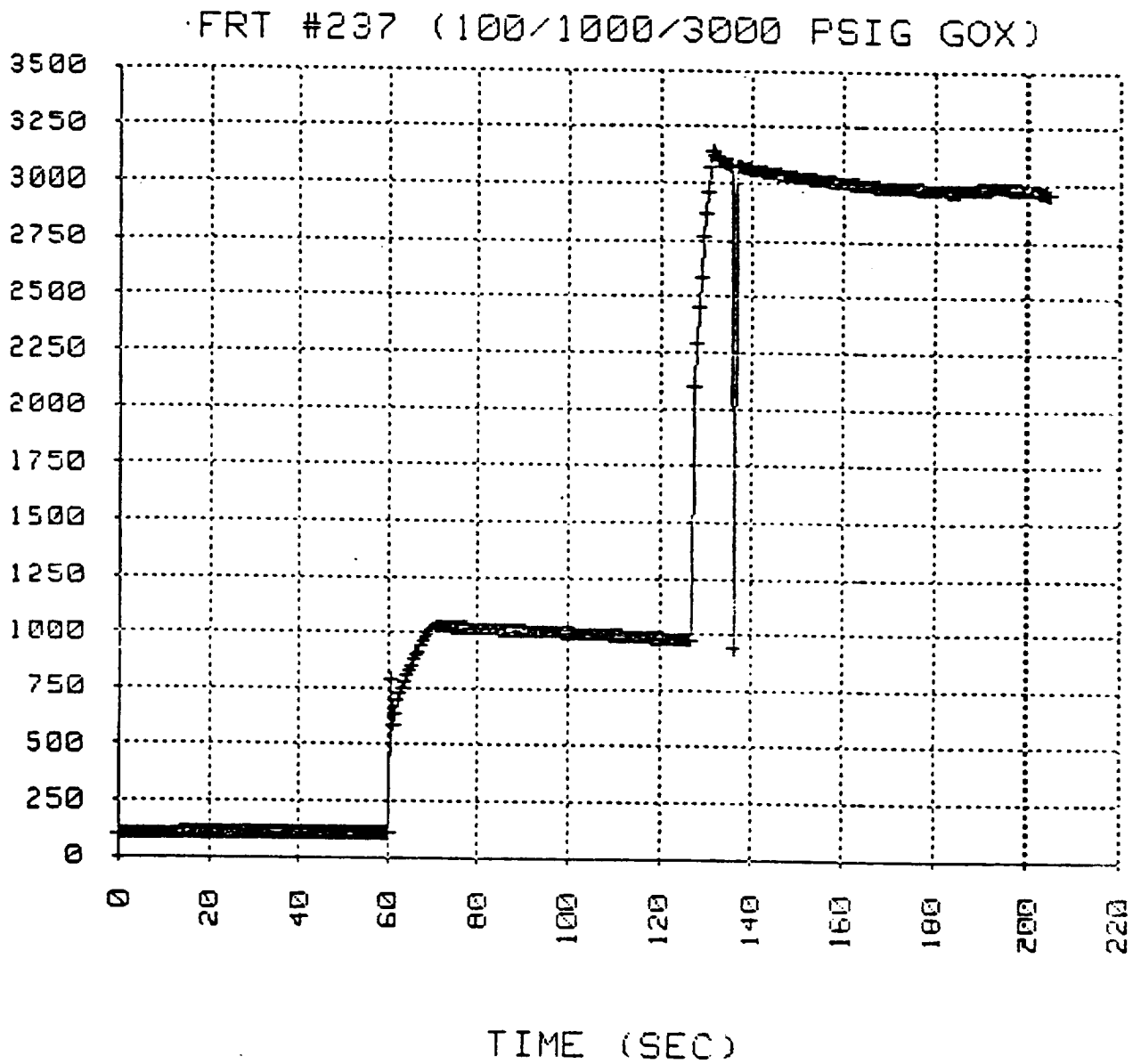


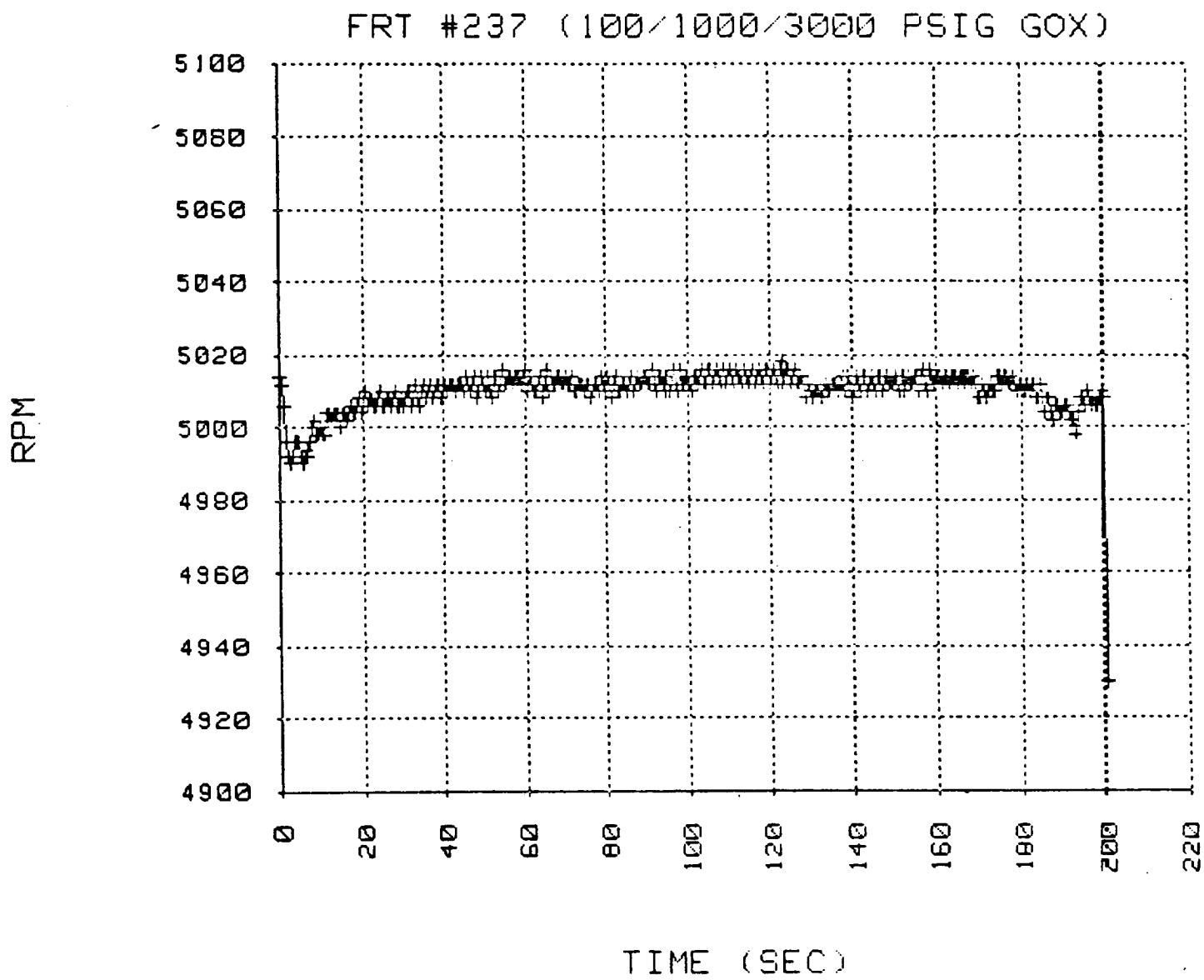
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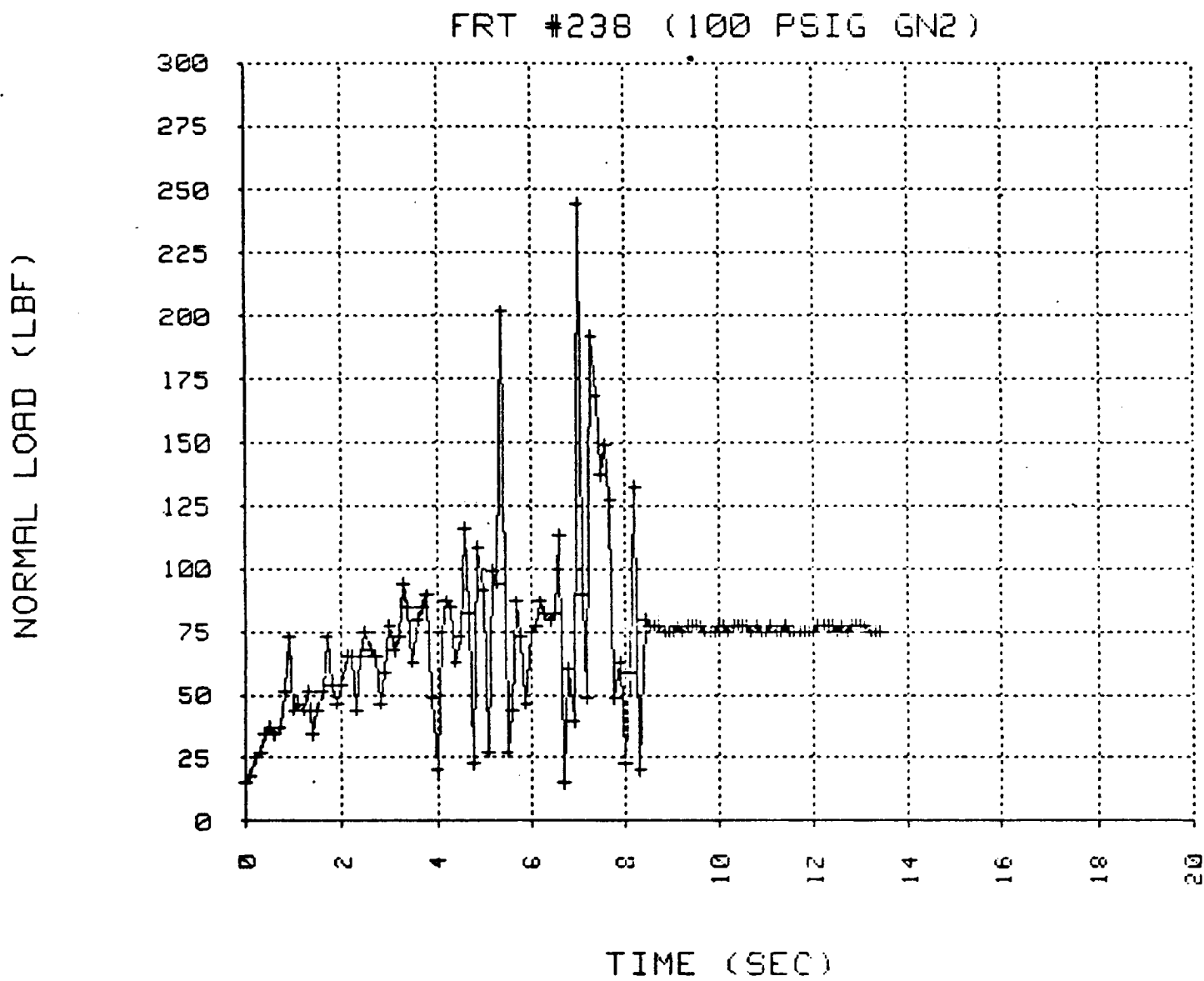


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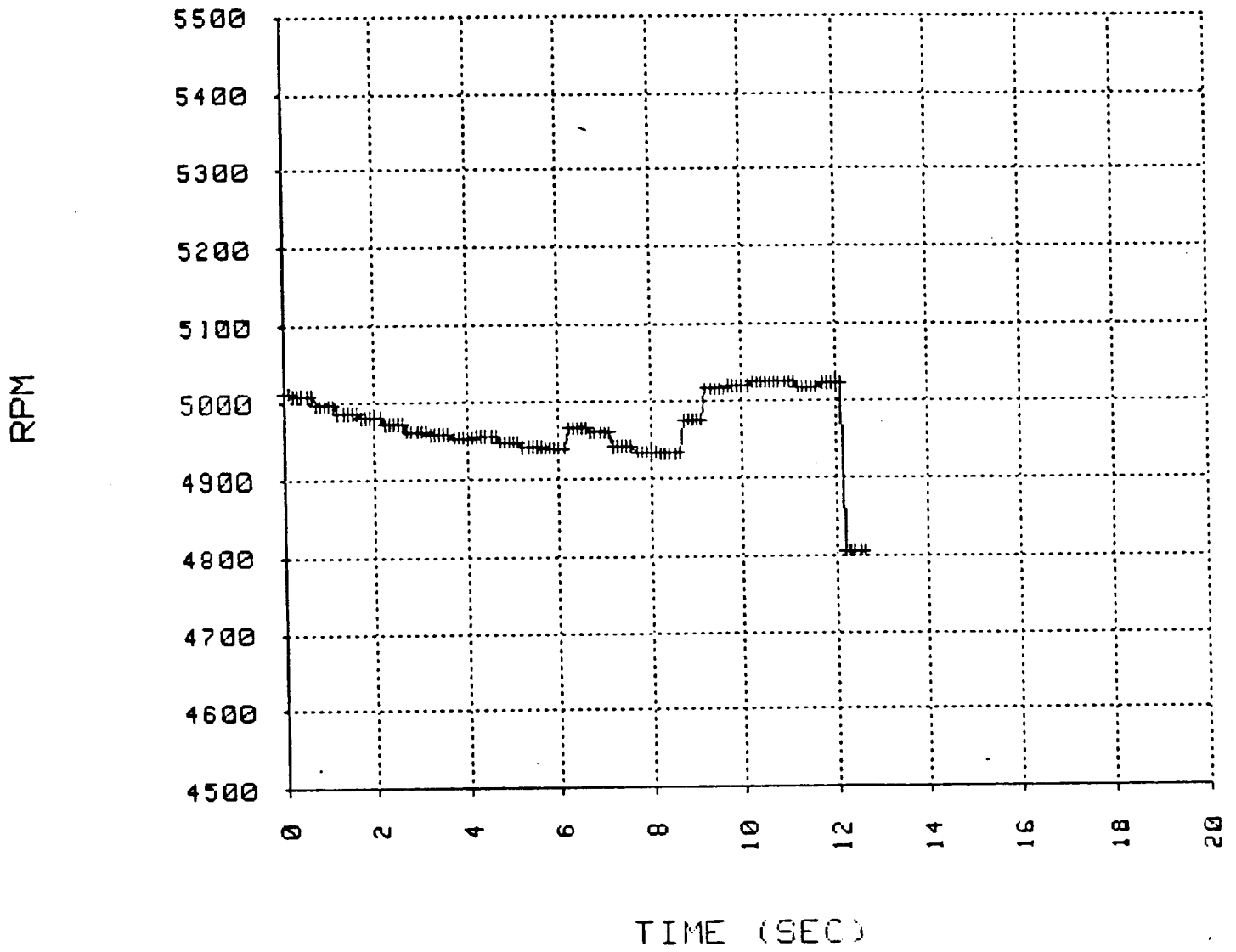
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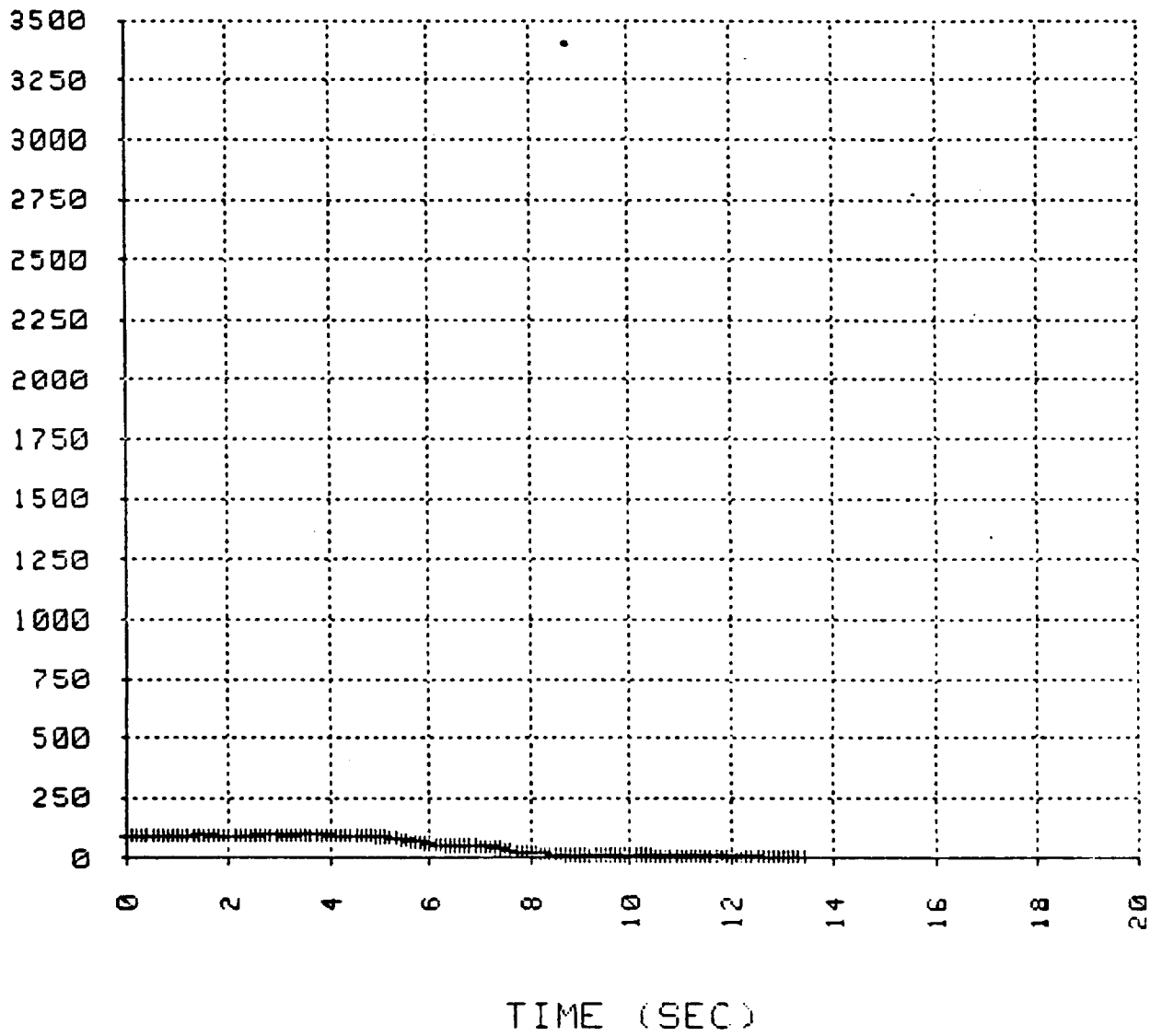


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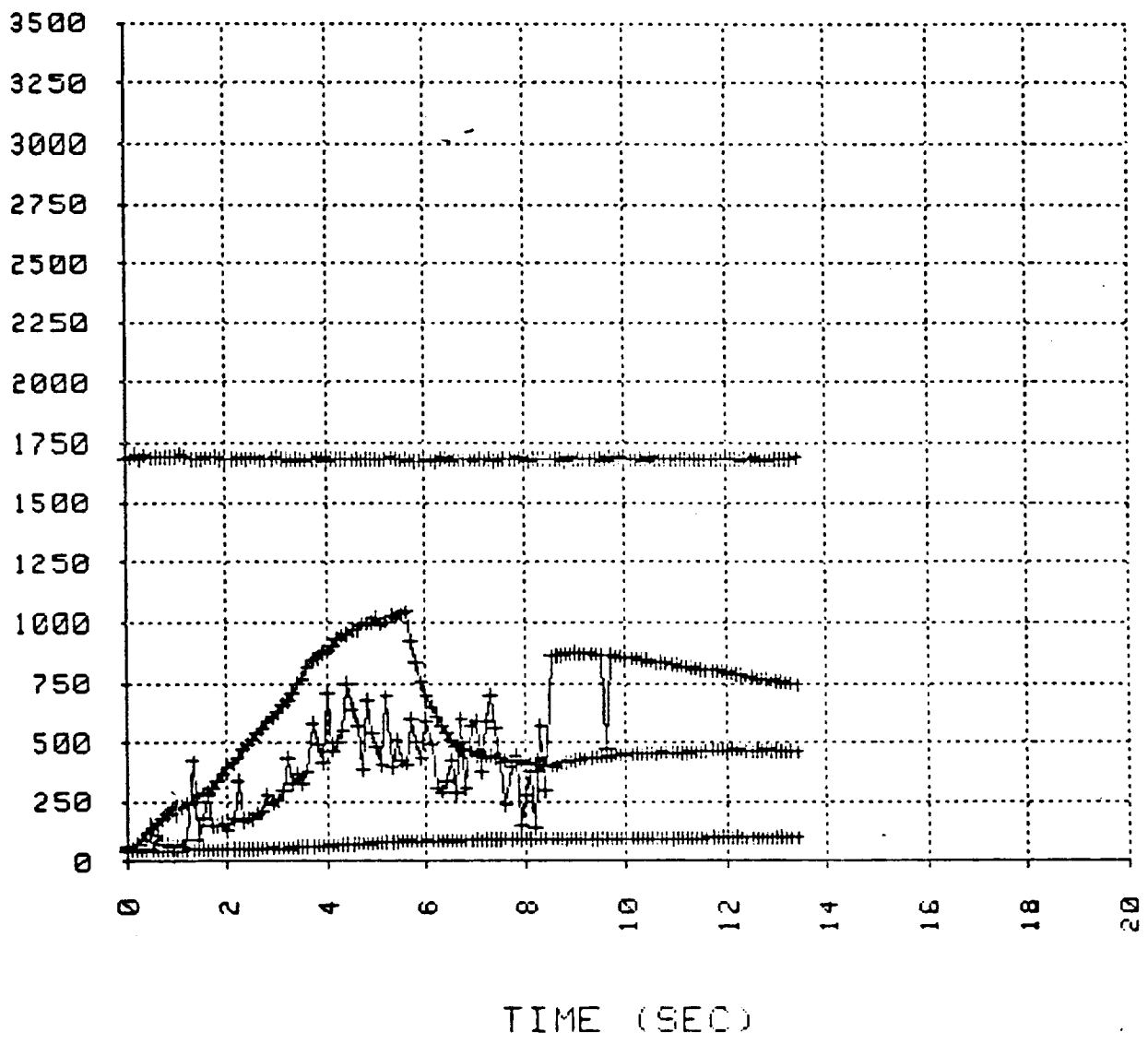
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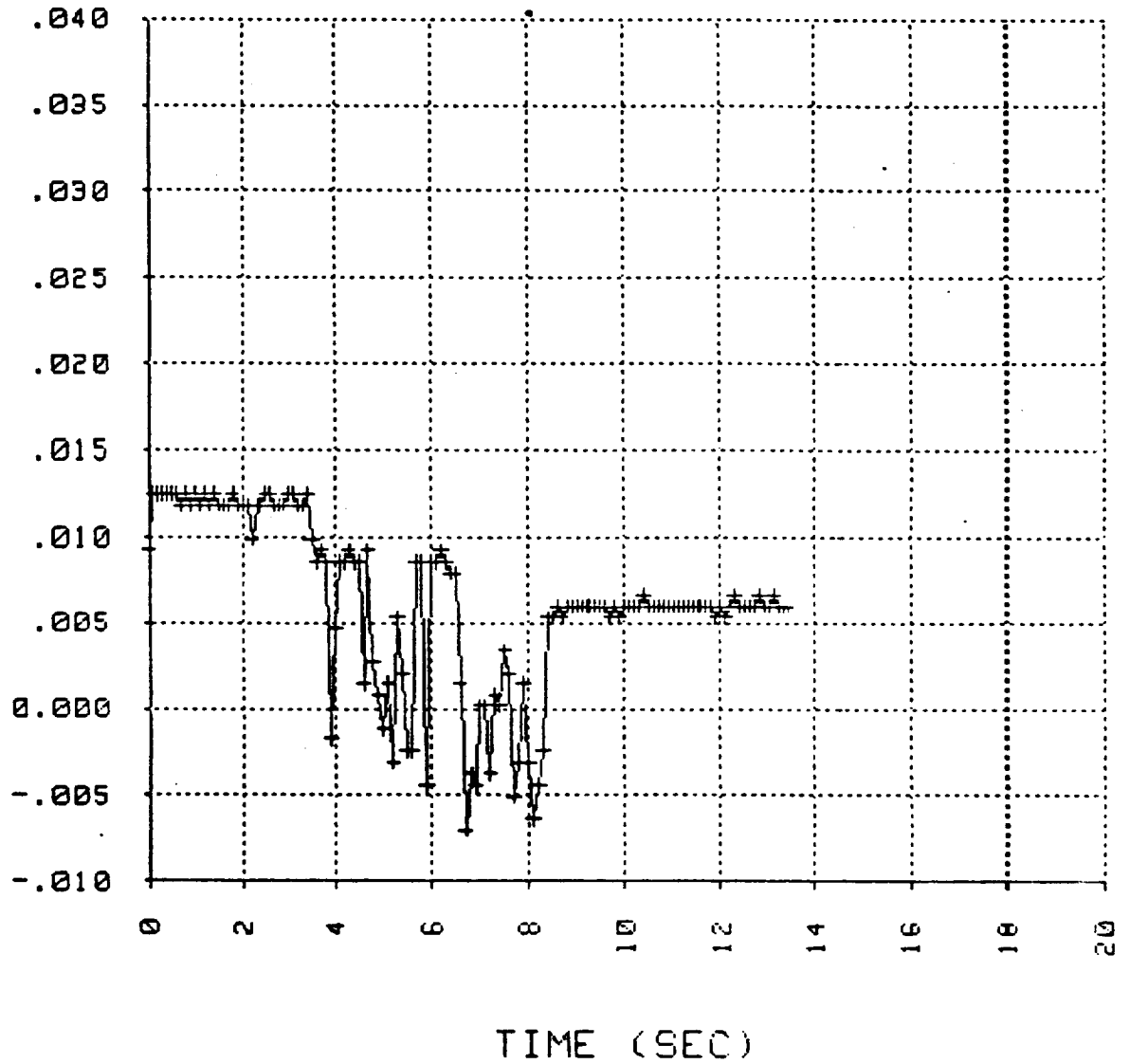
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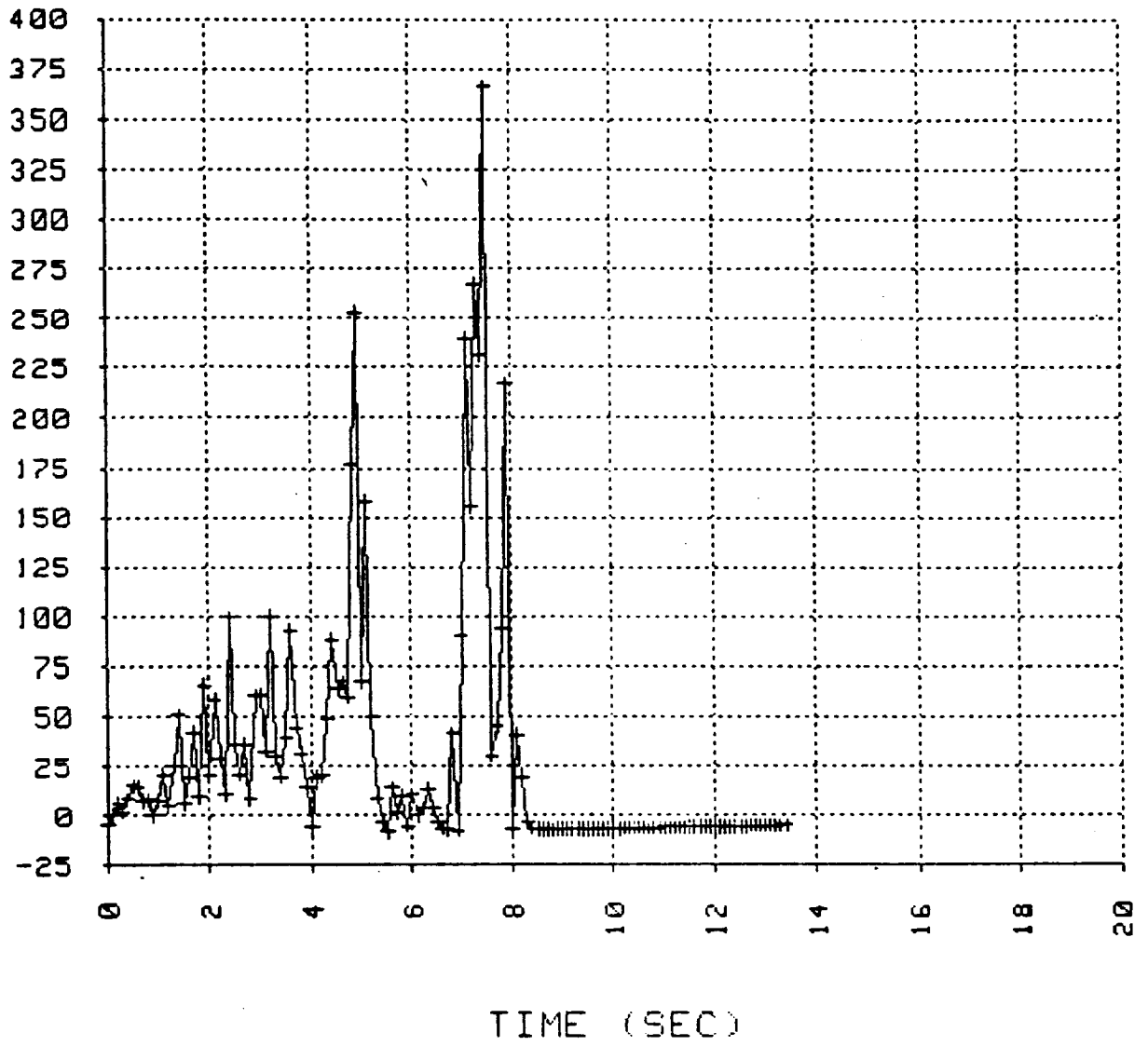
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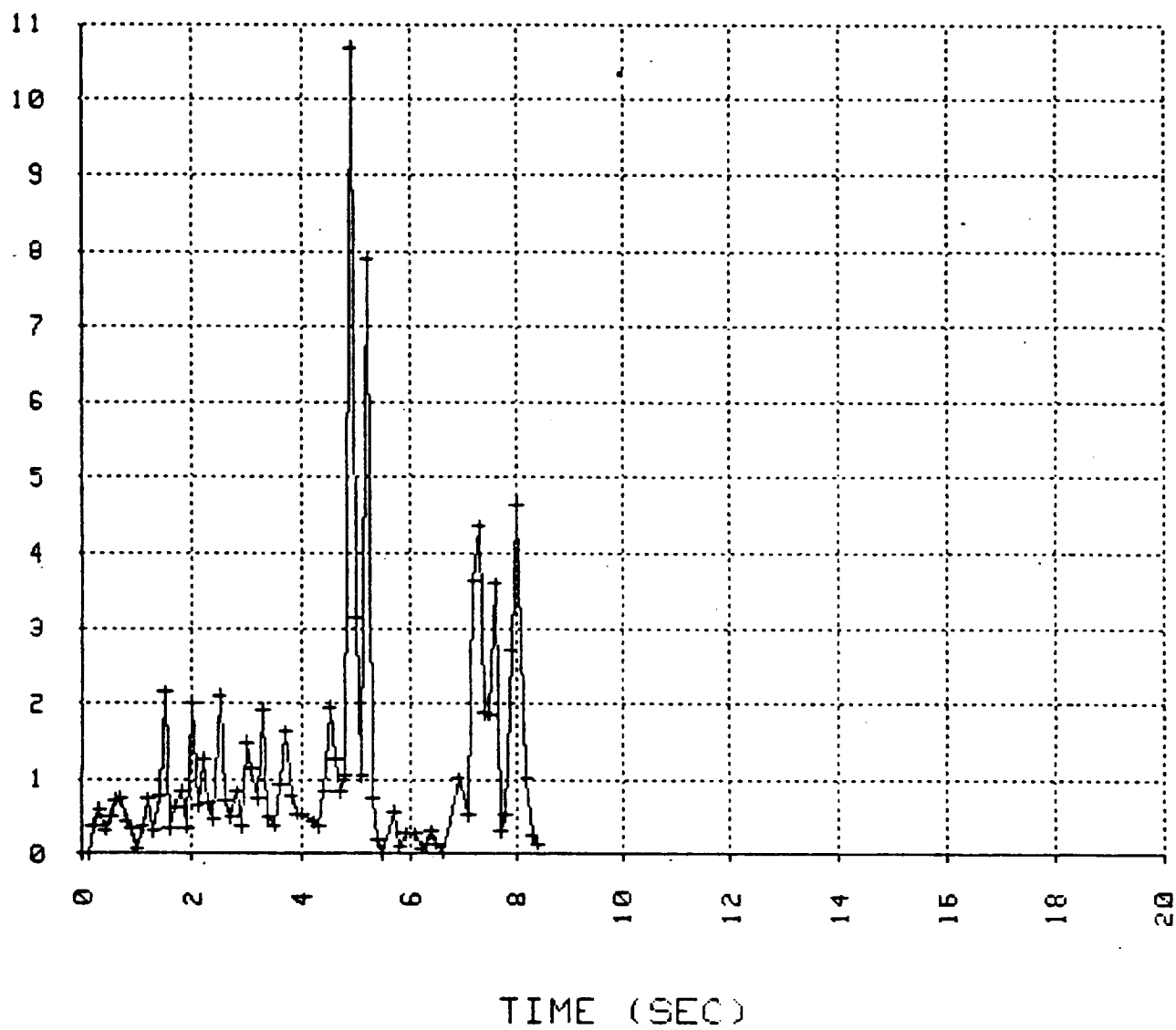
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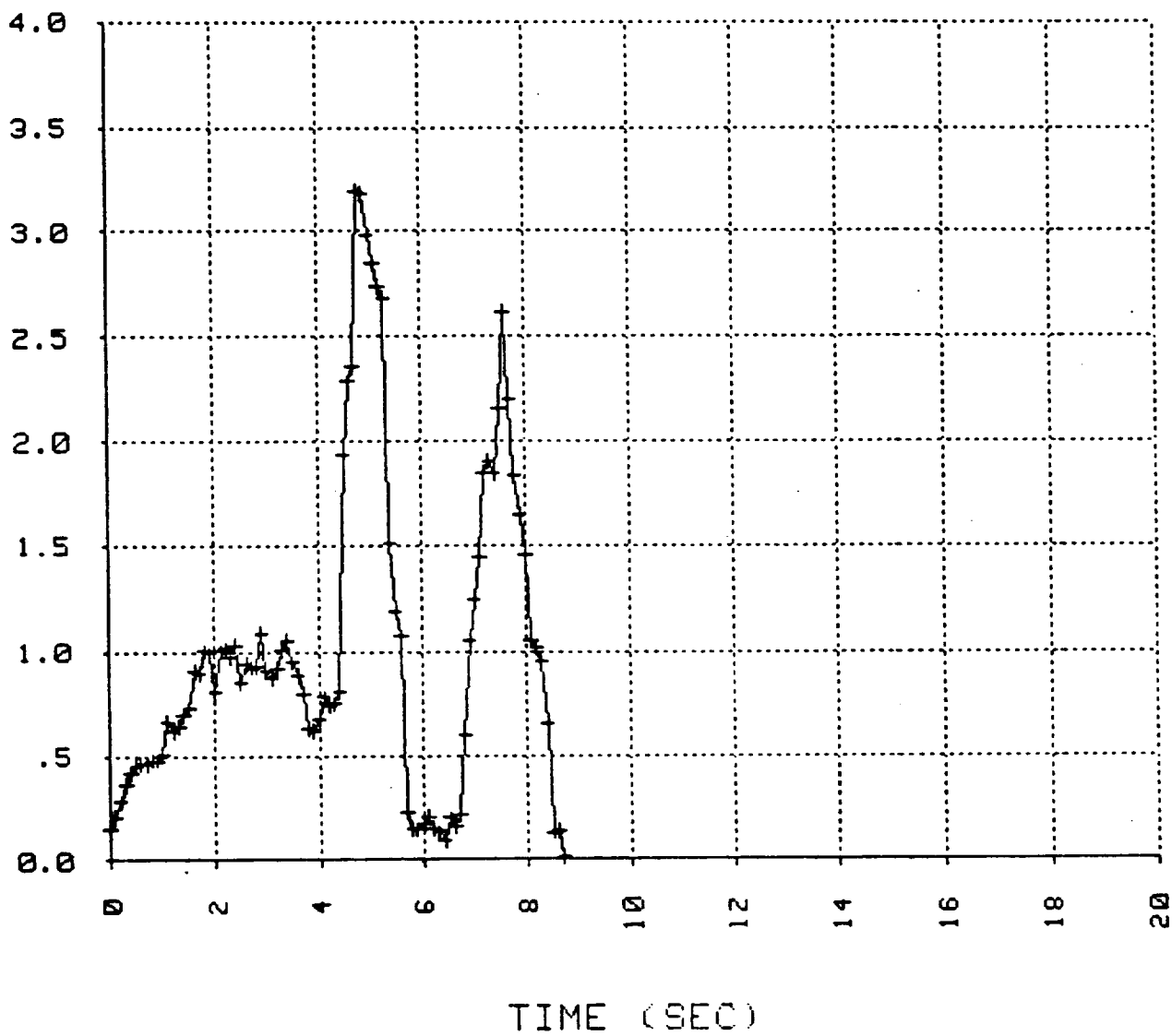
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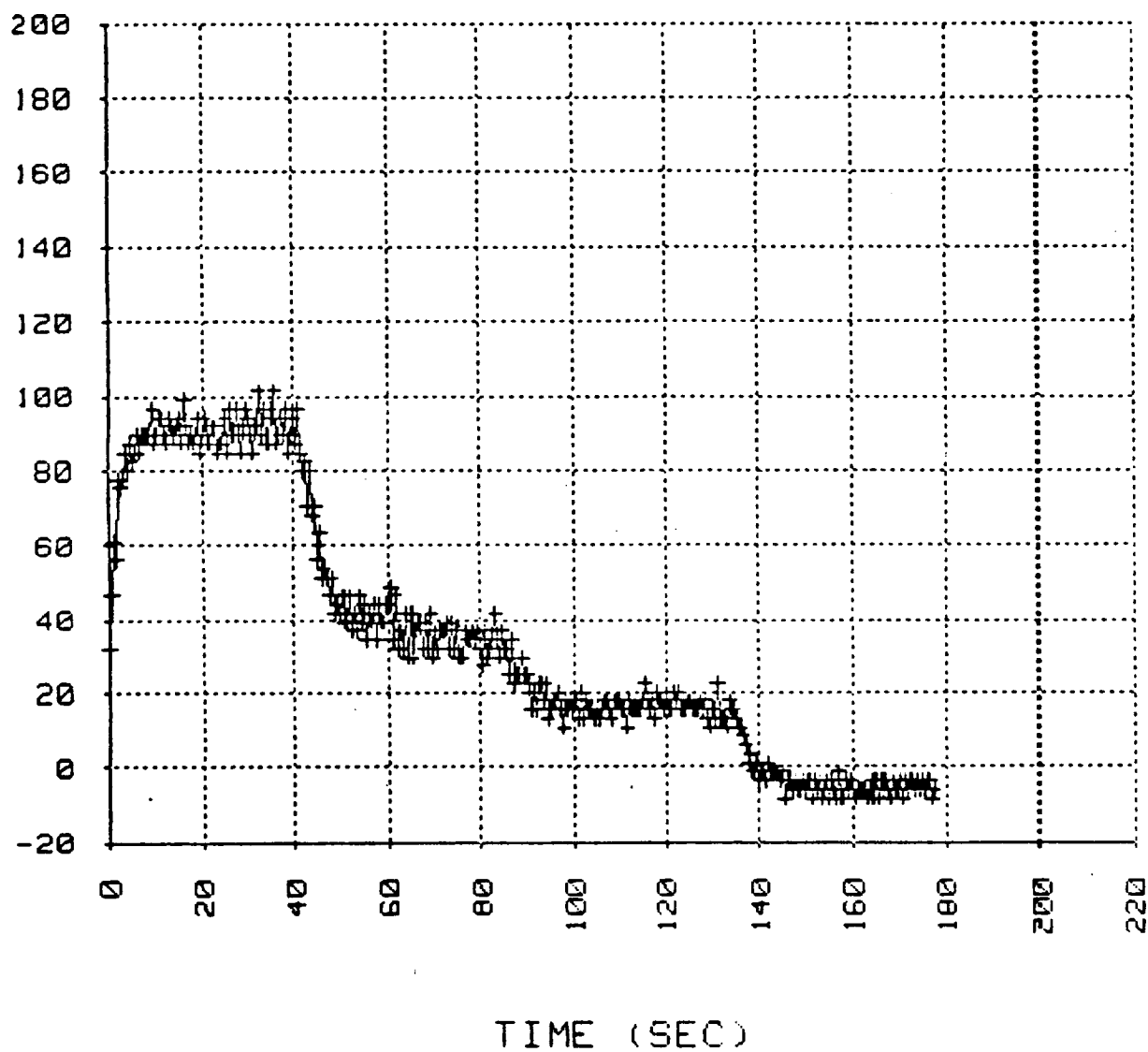
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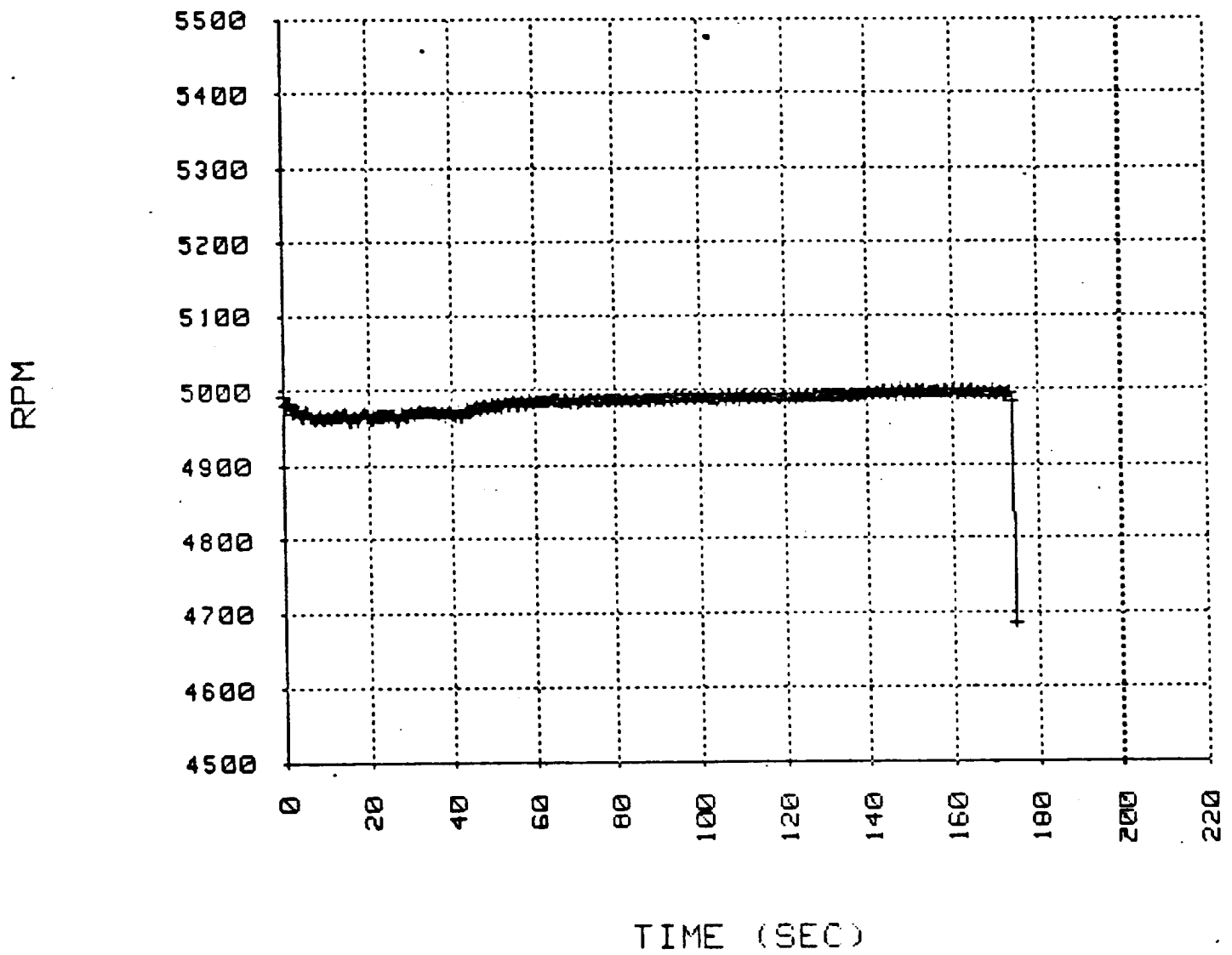


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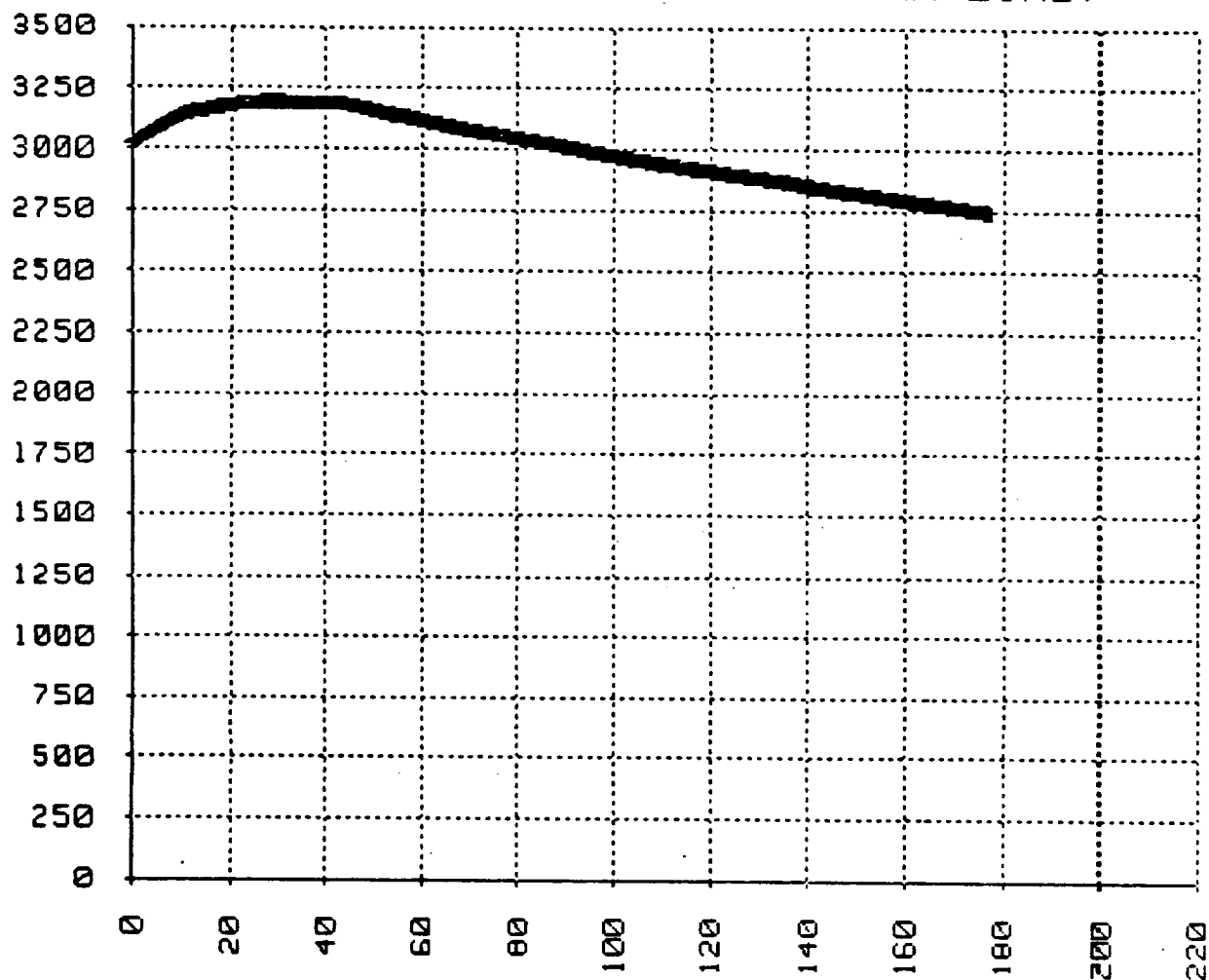


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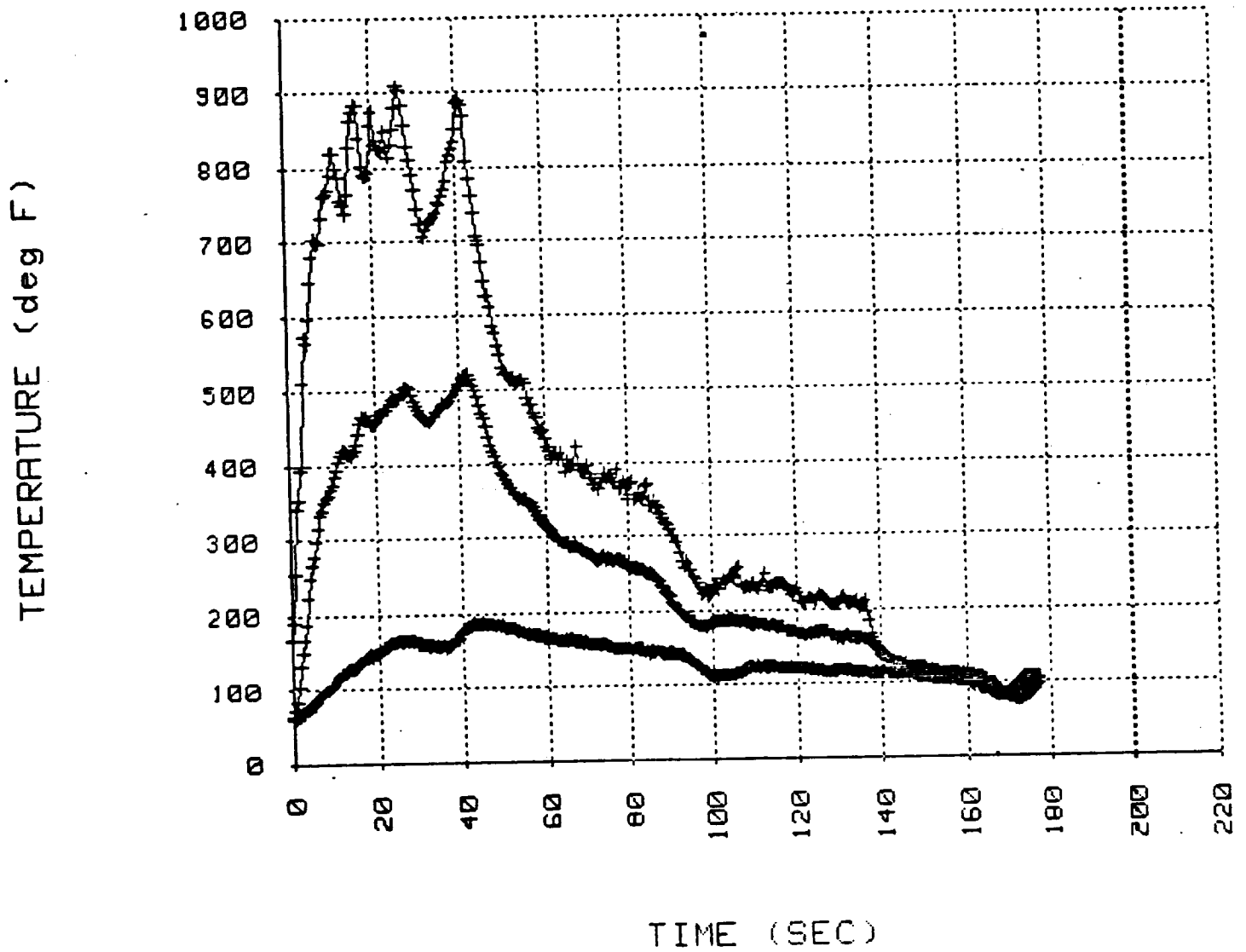
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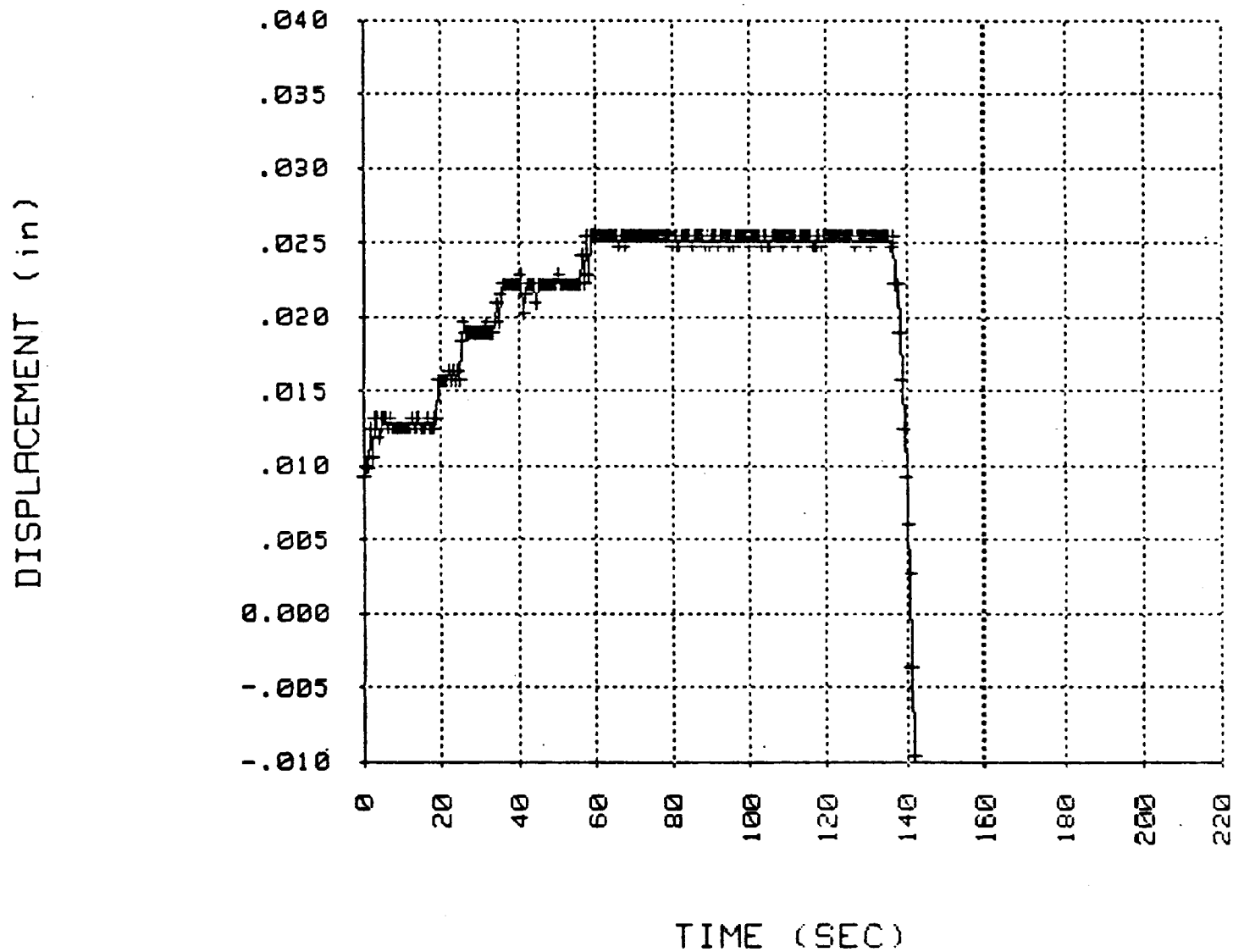
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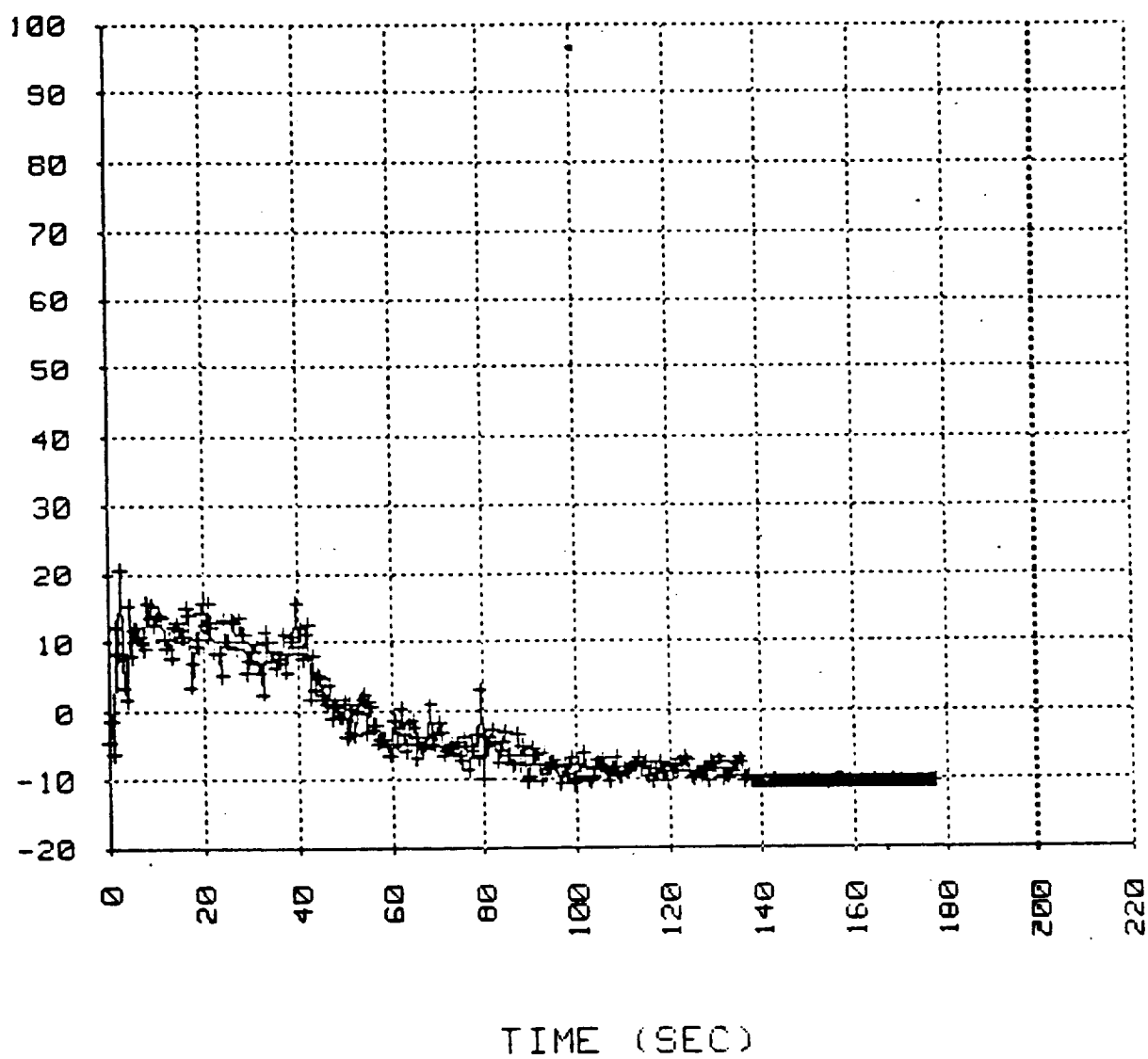
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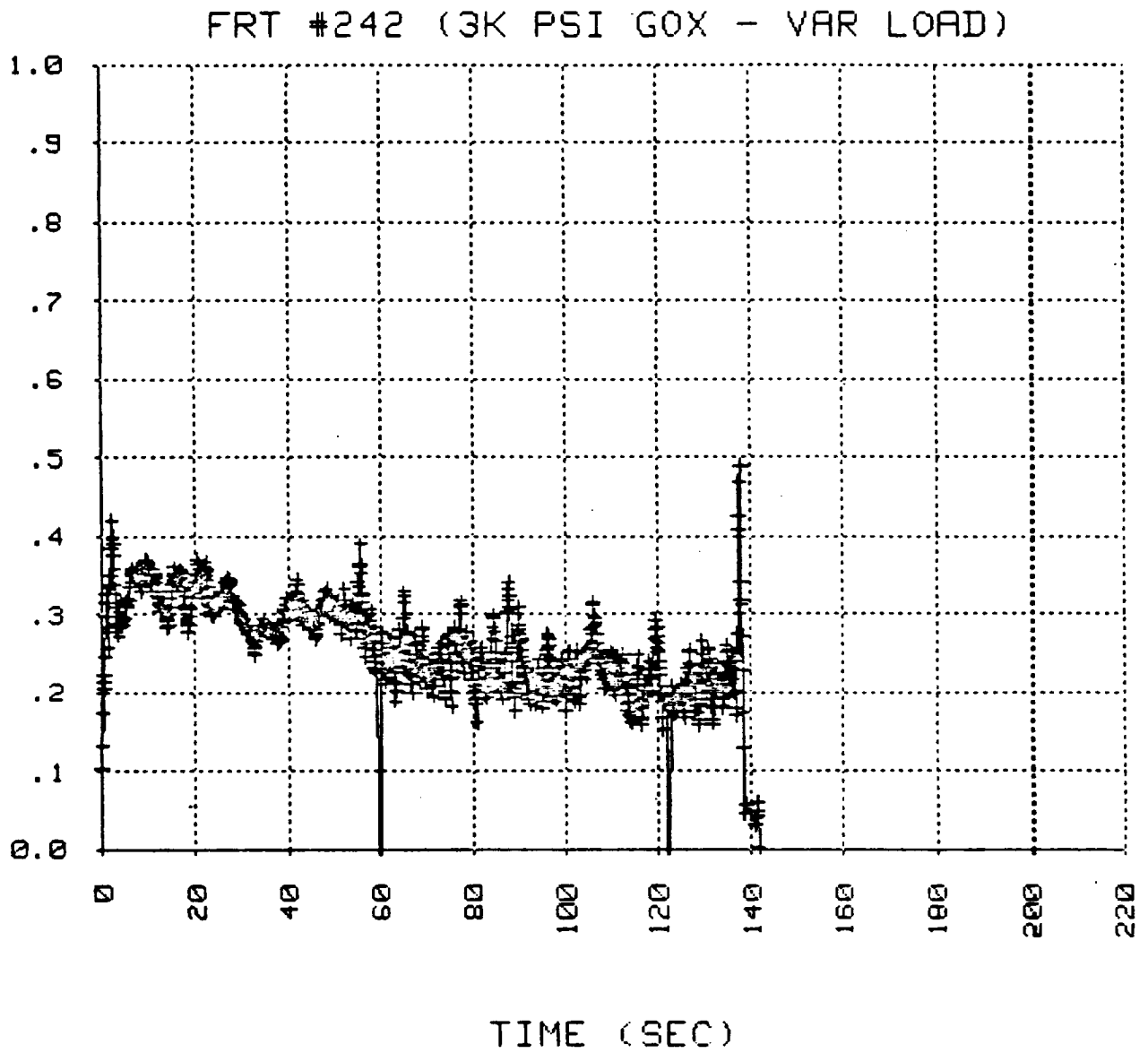
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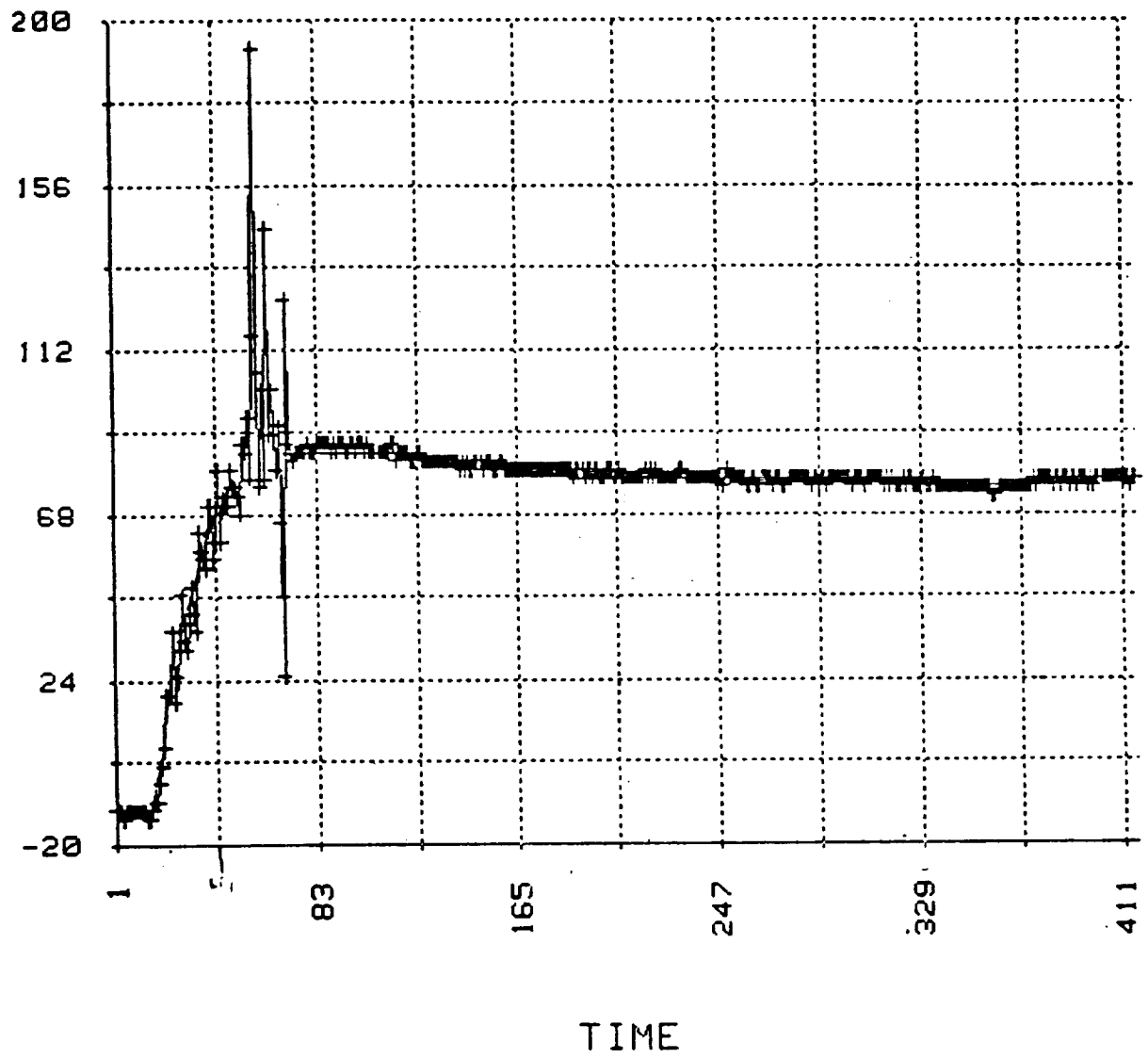
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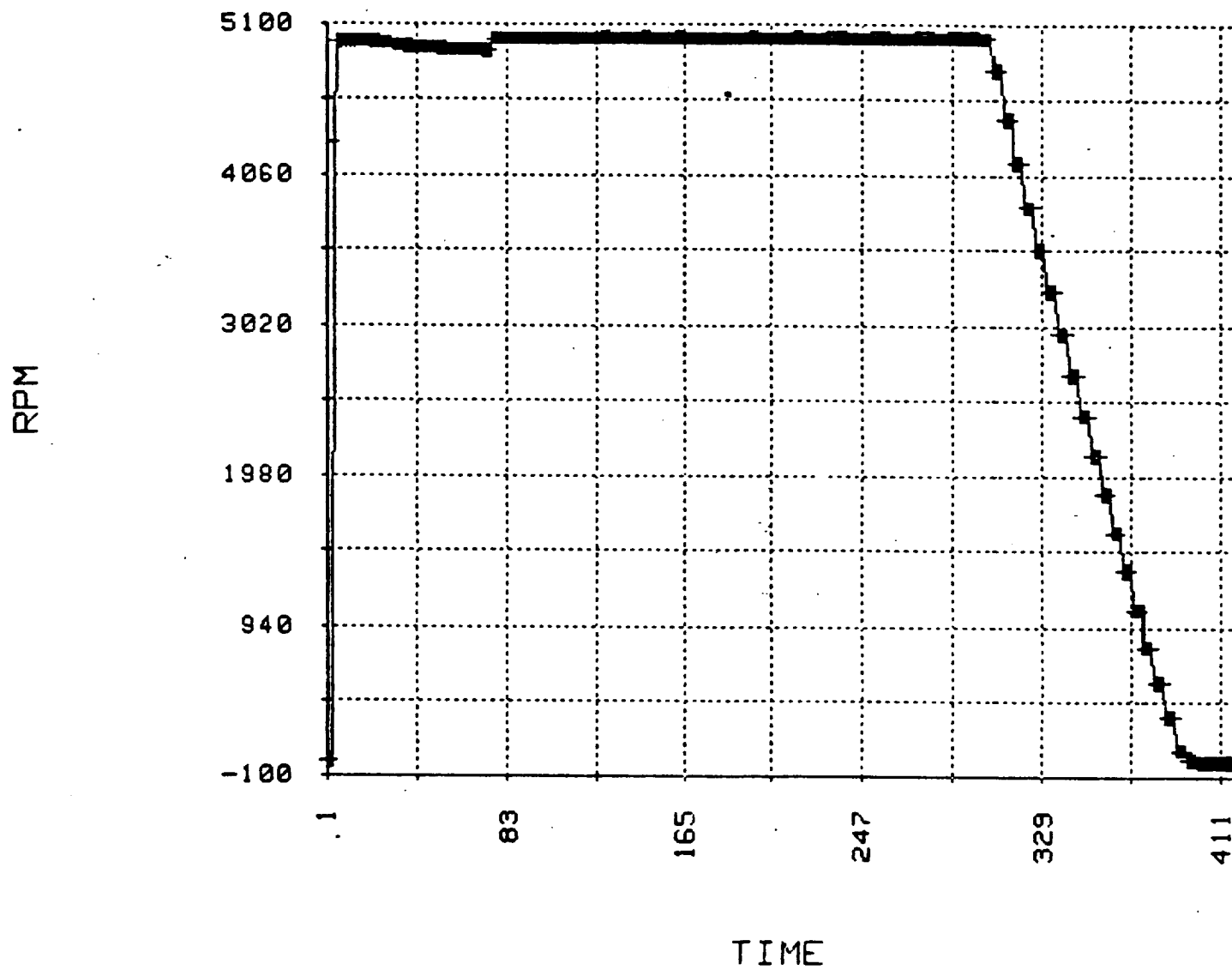
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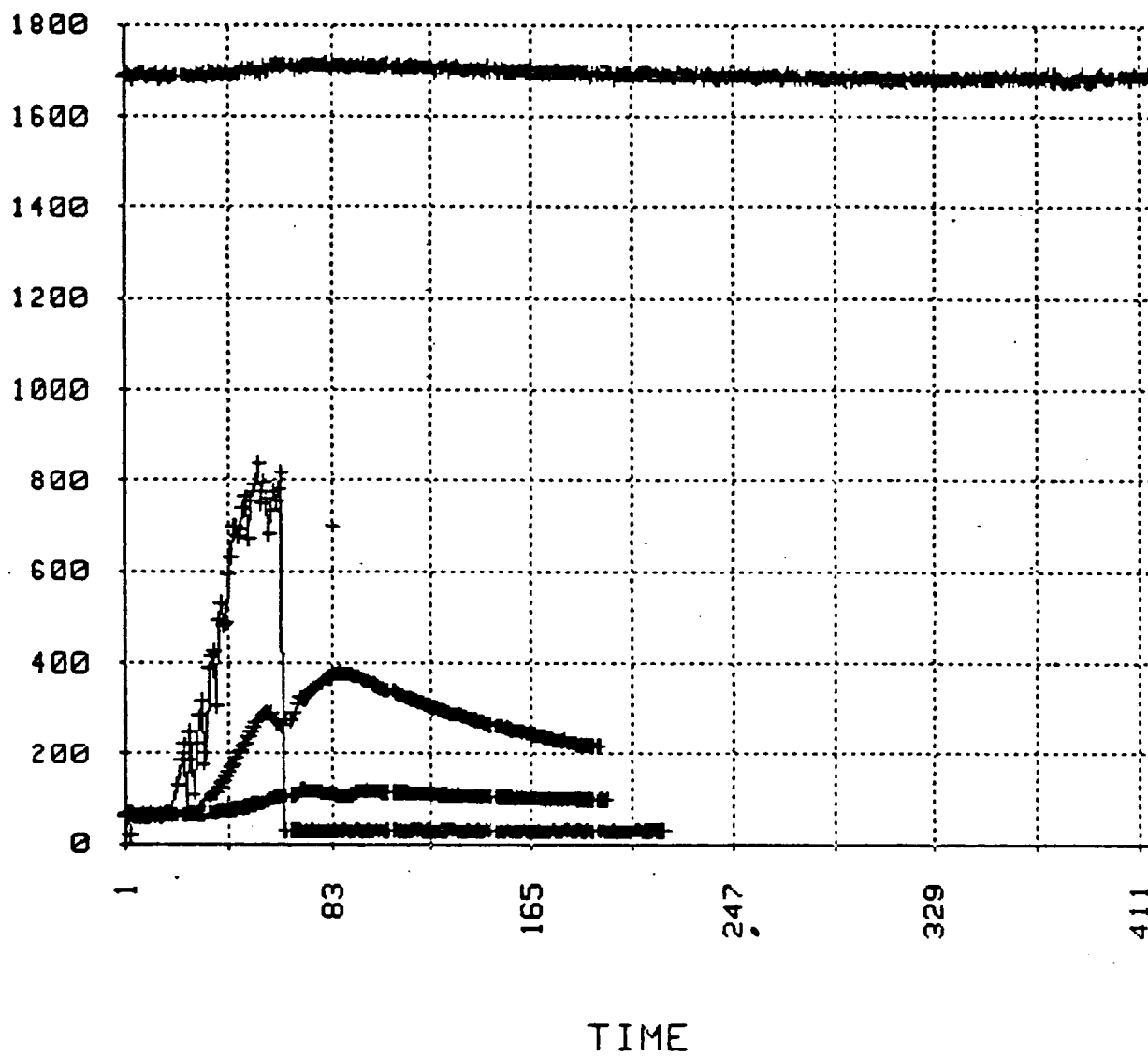


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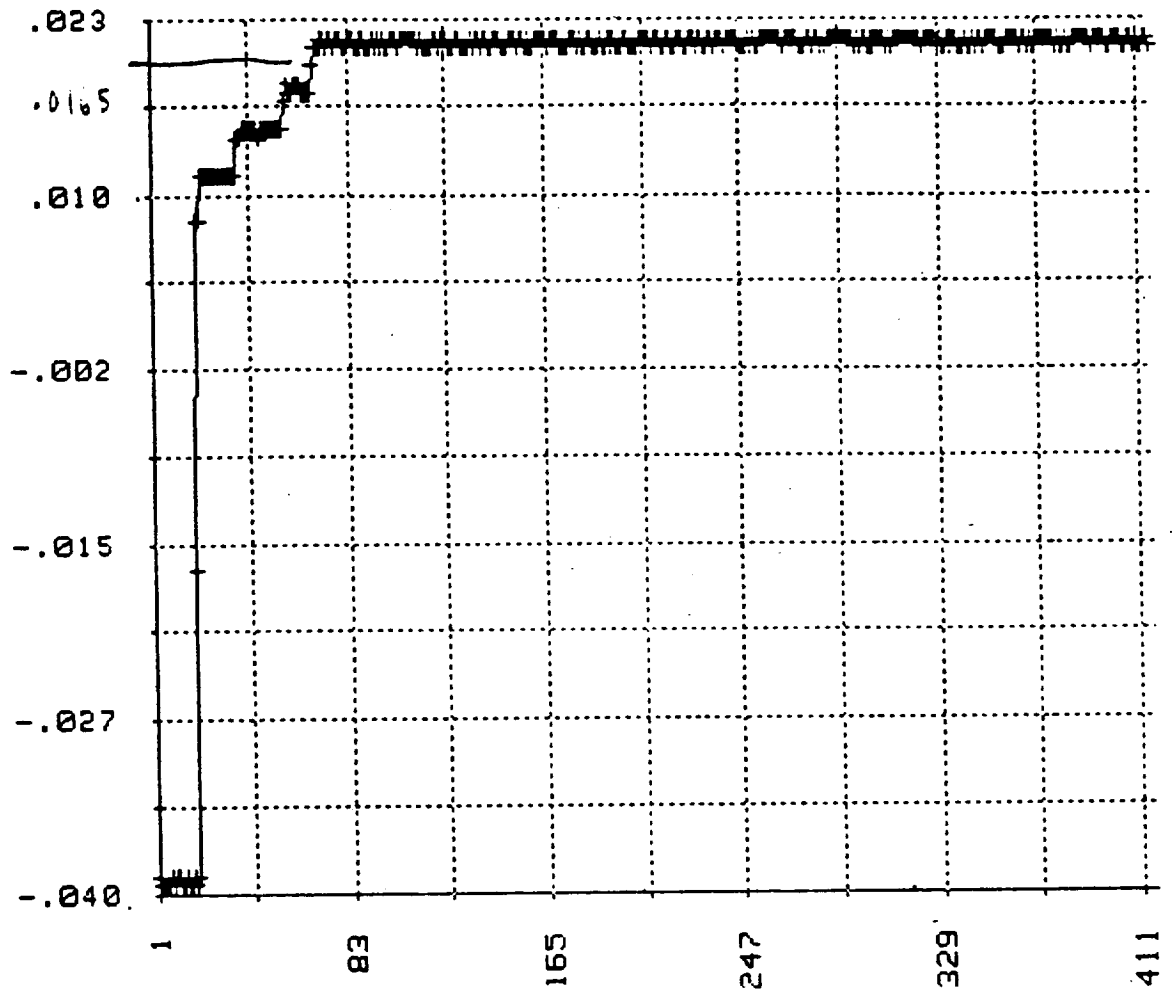
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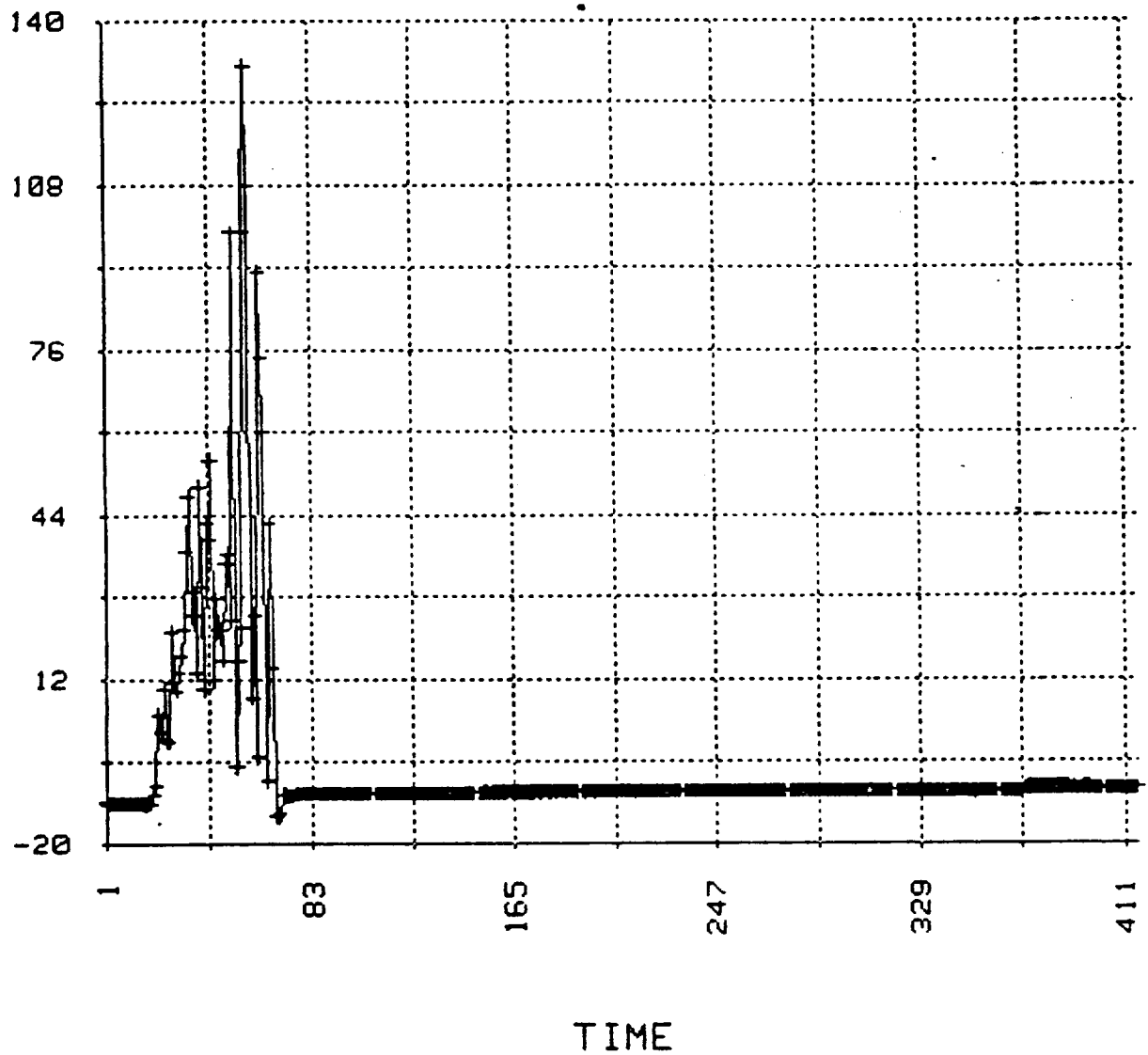
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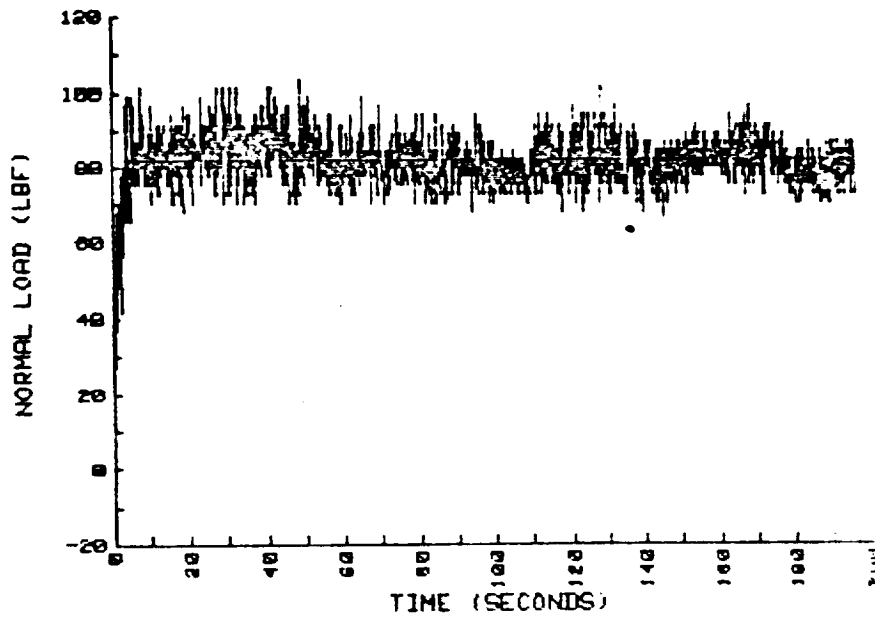
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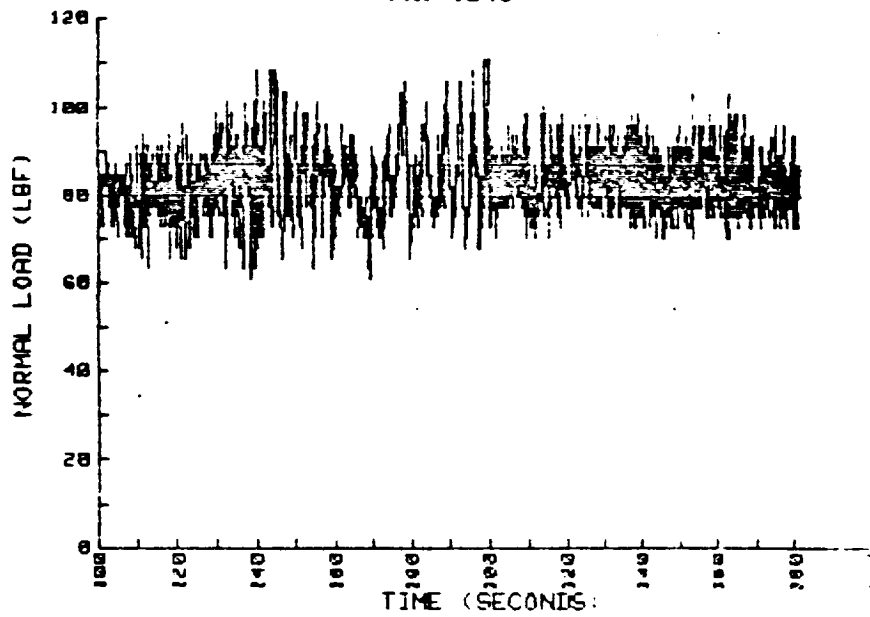


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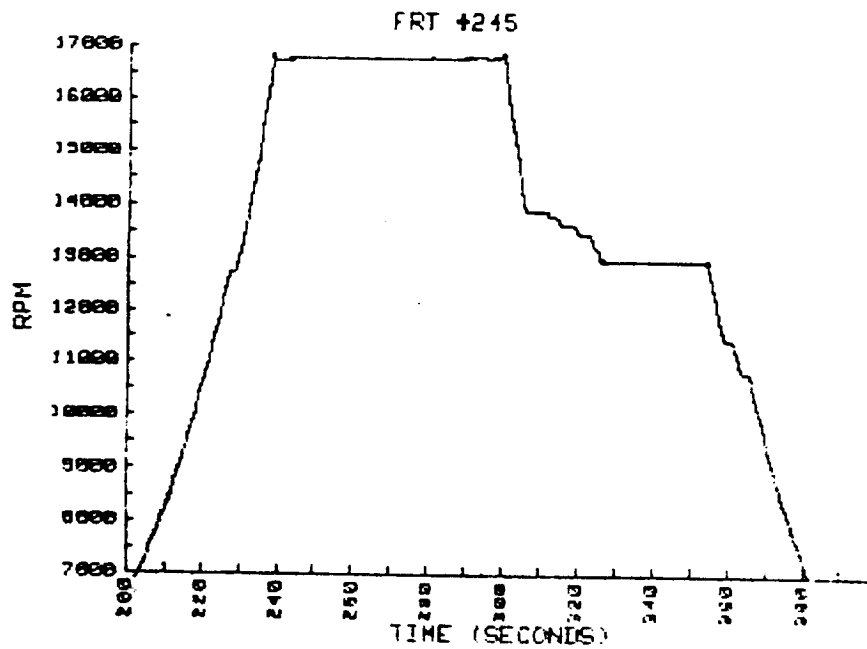
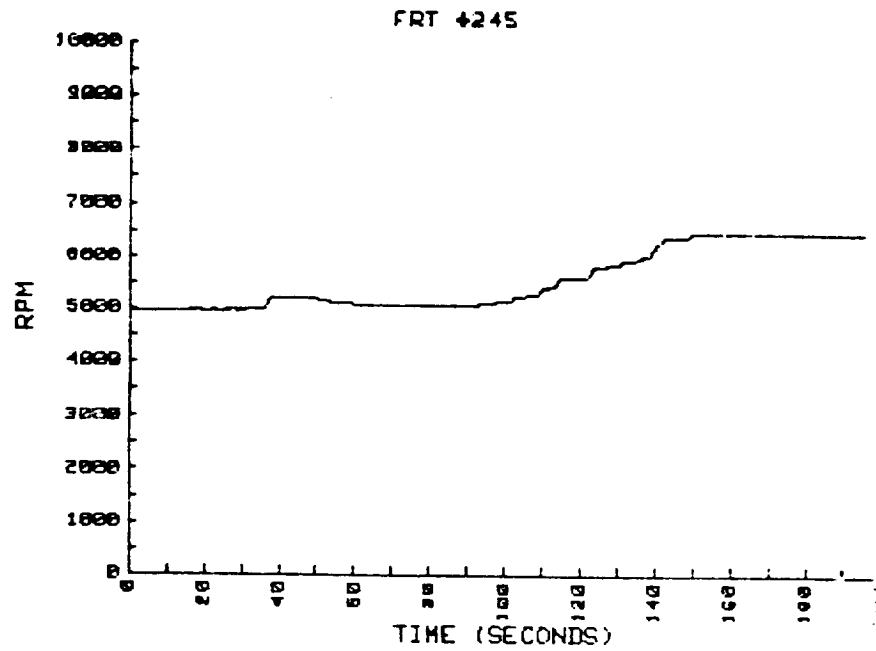
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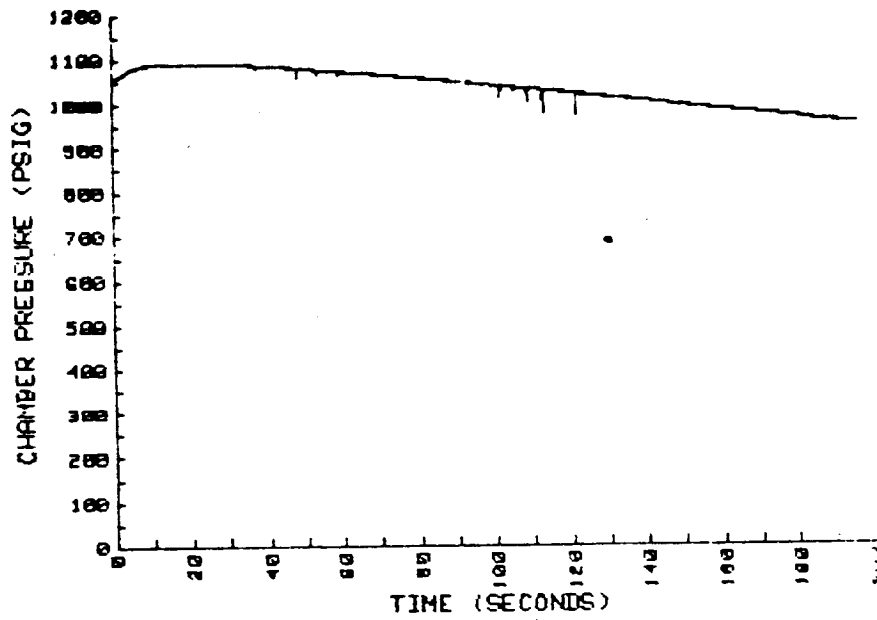
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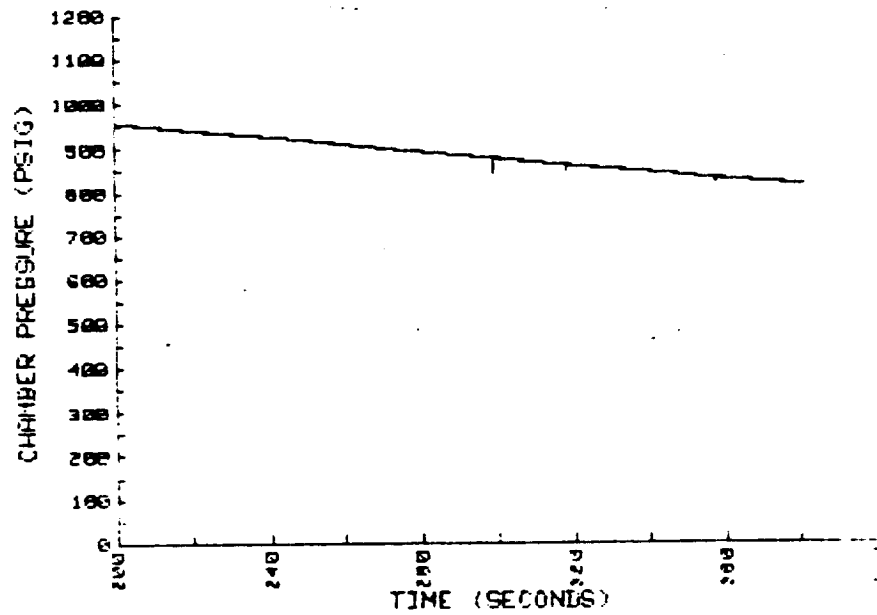
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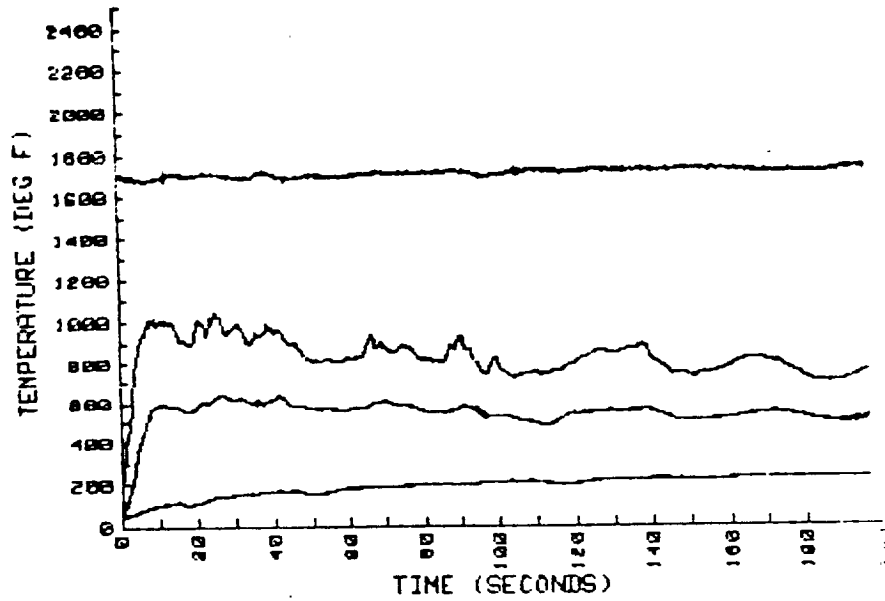


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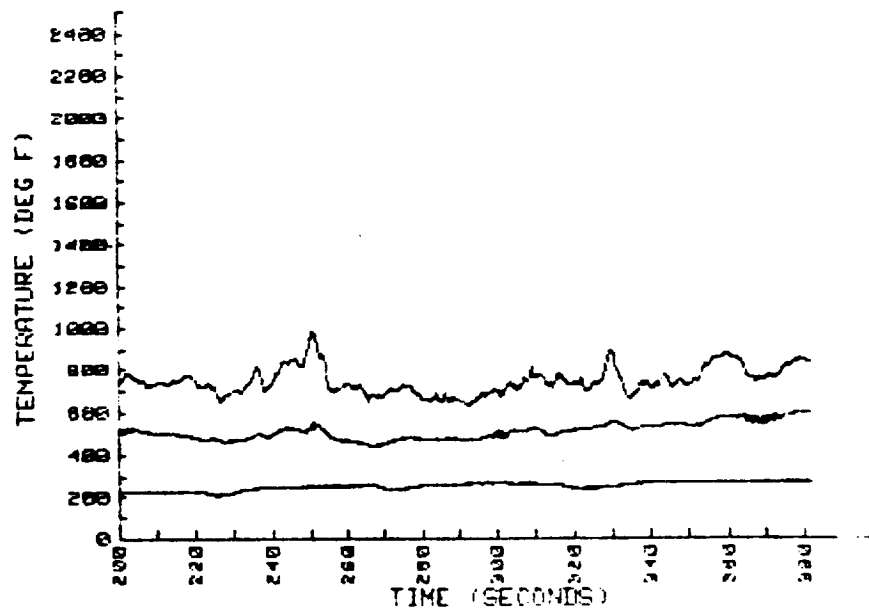
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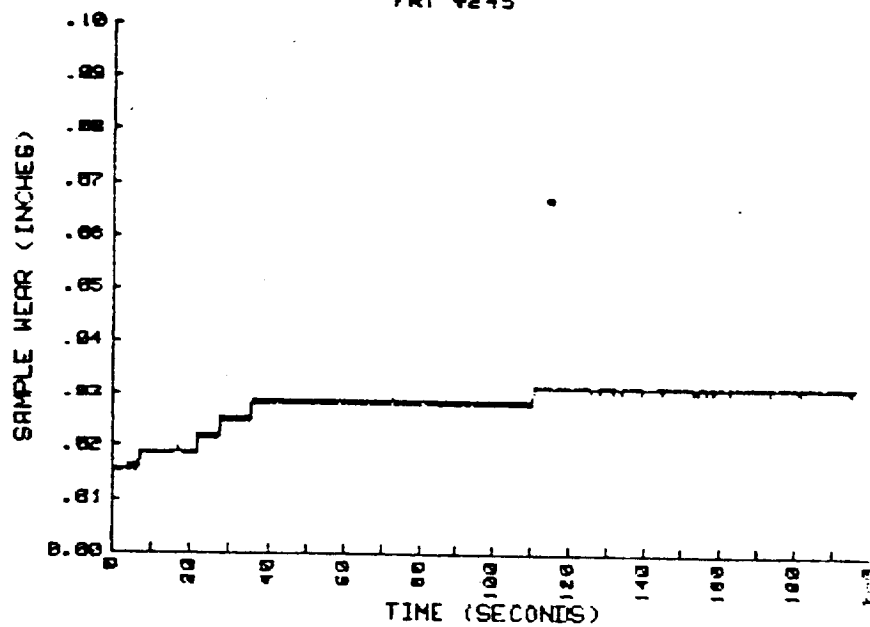


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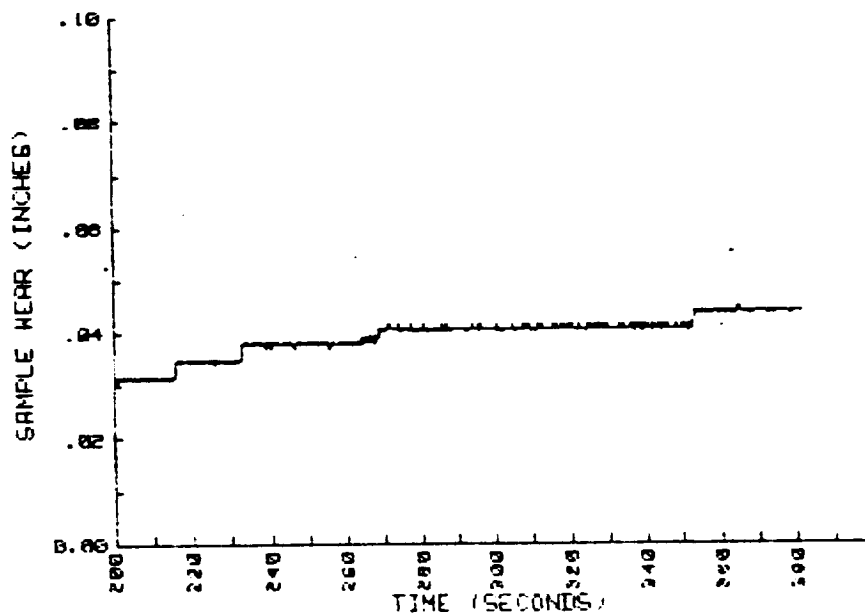


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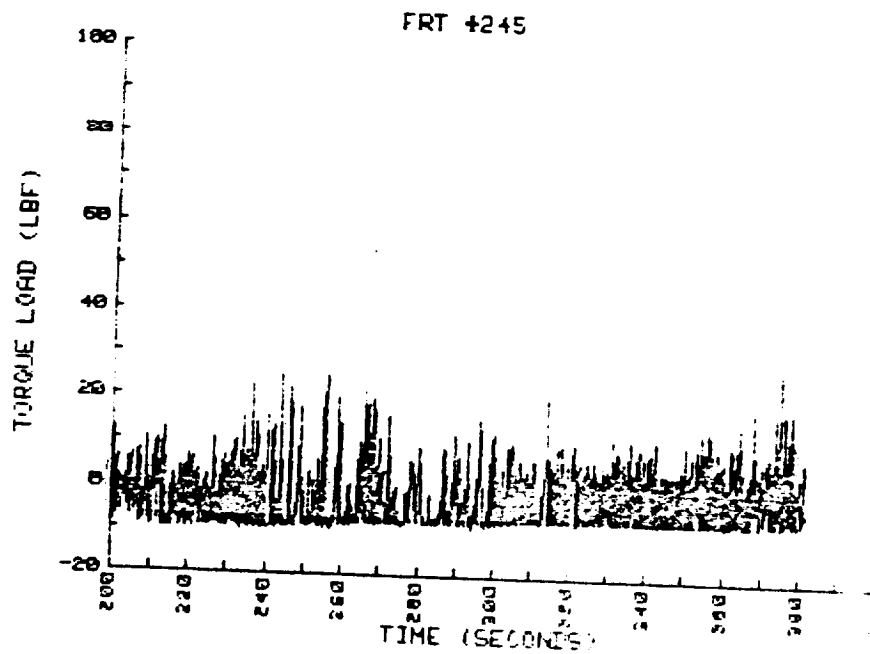
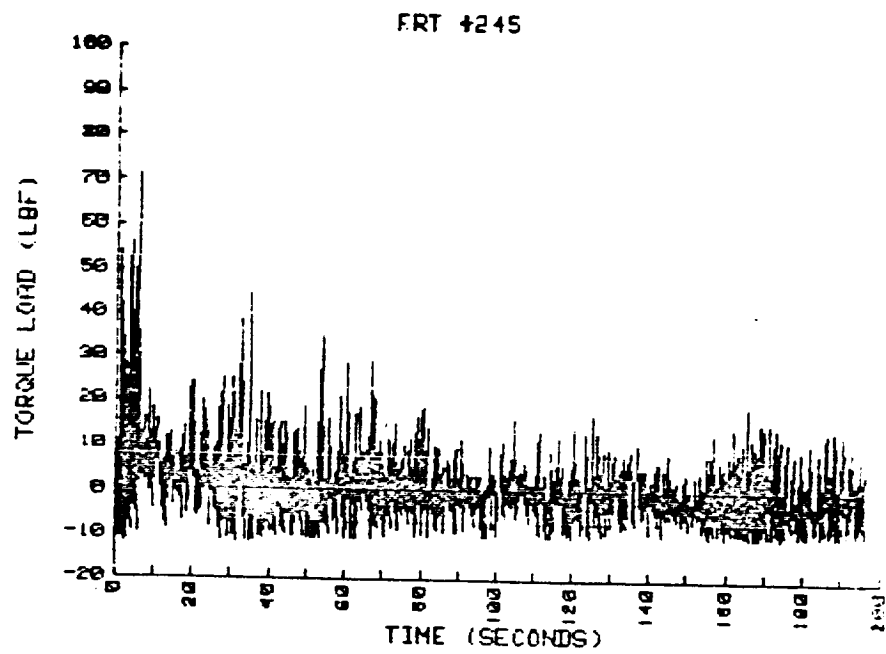
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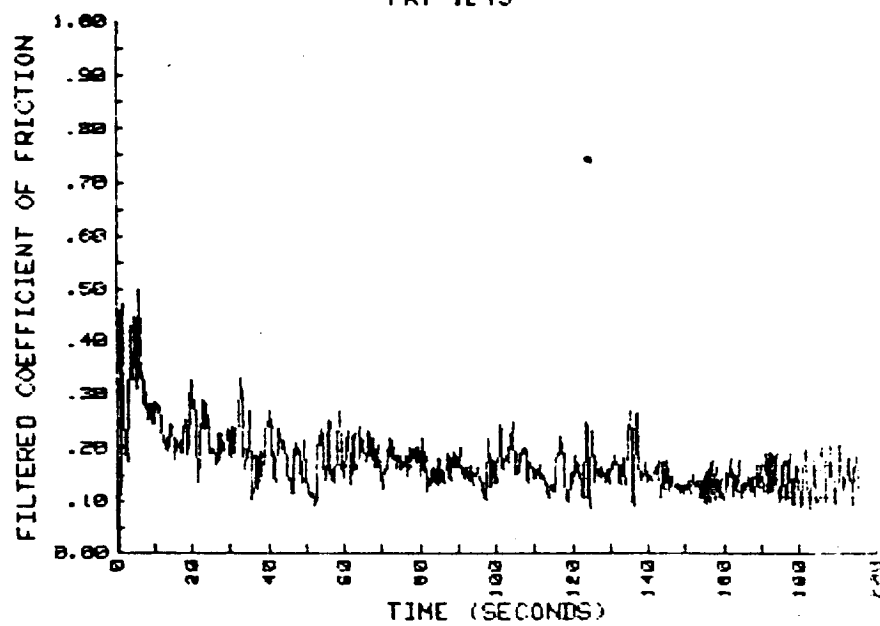


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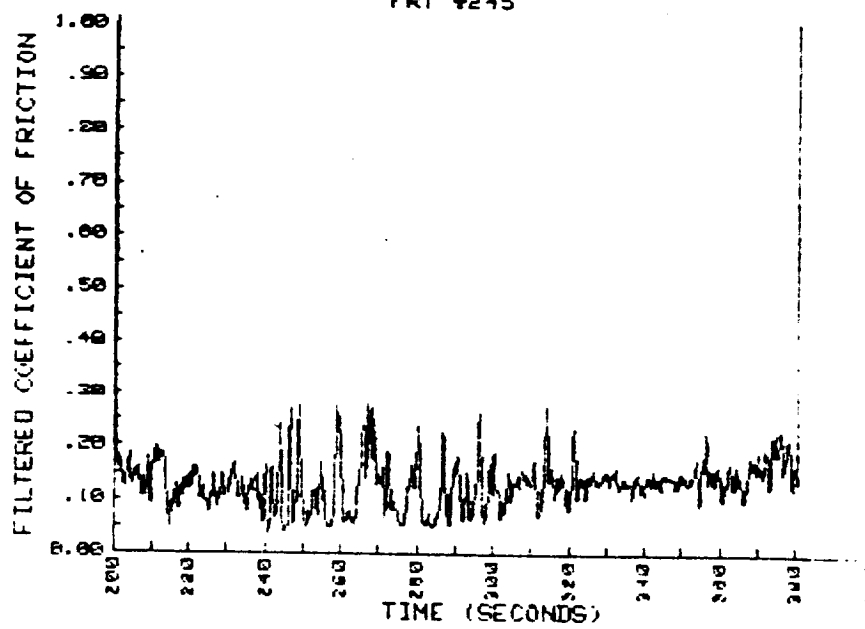


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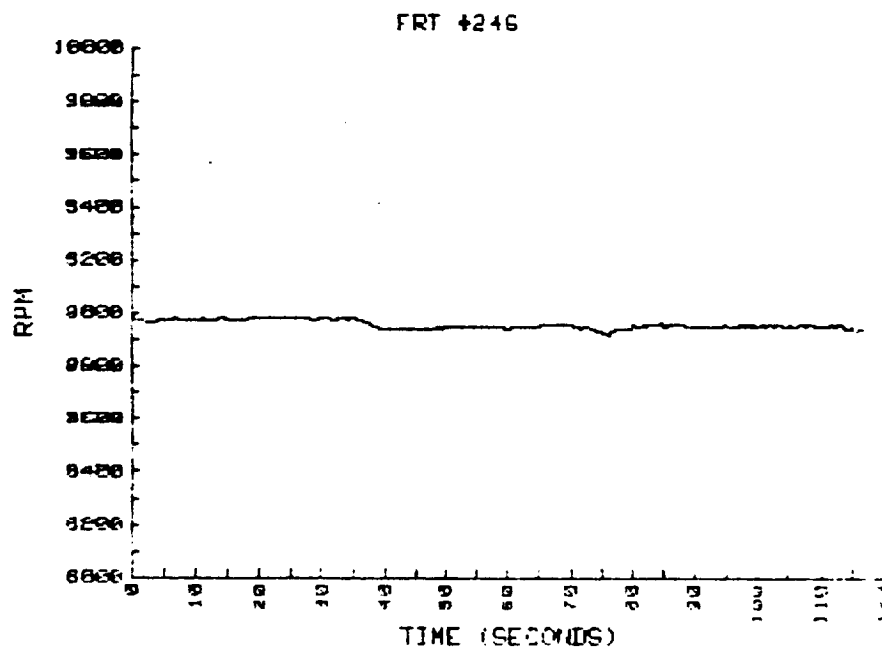
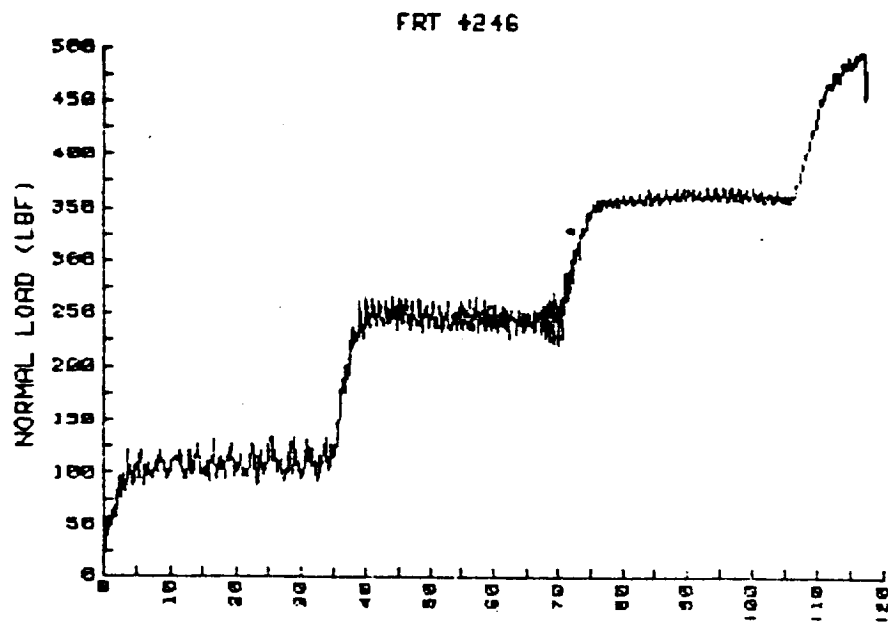
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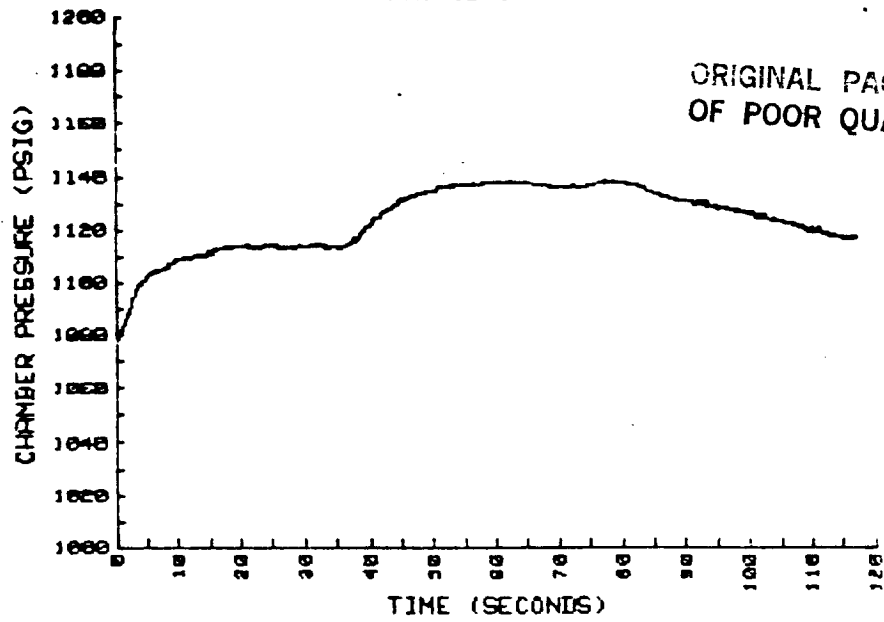
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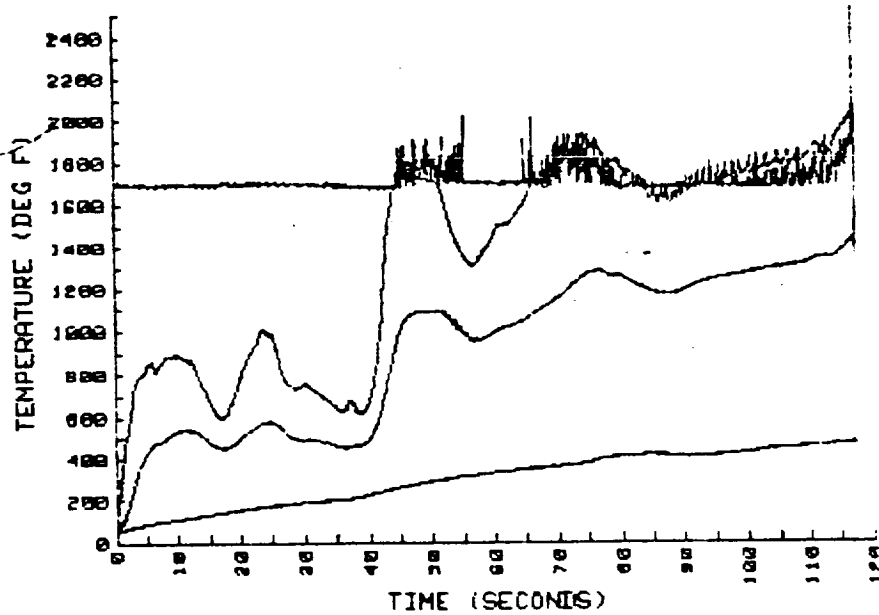
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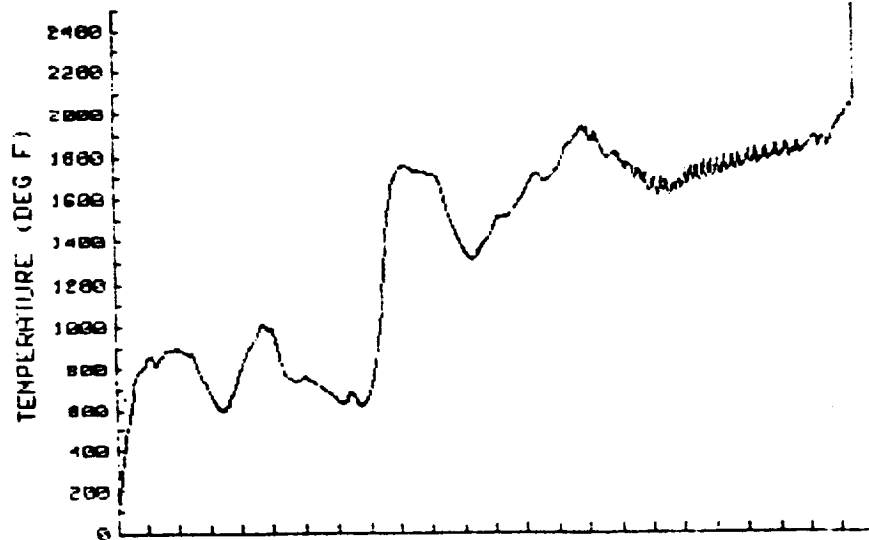
FRT 4246



FRT 4246



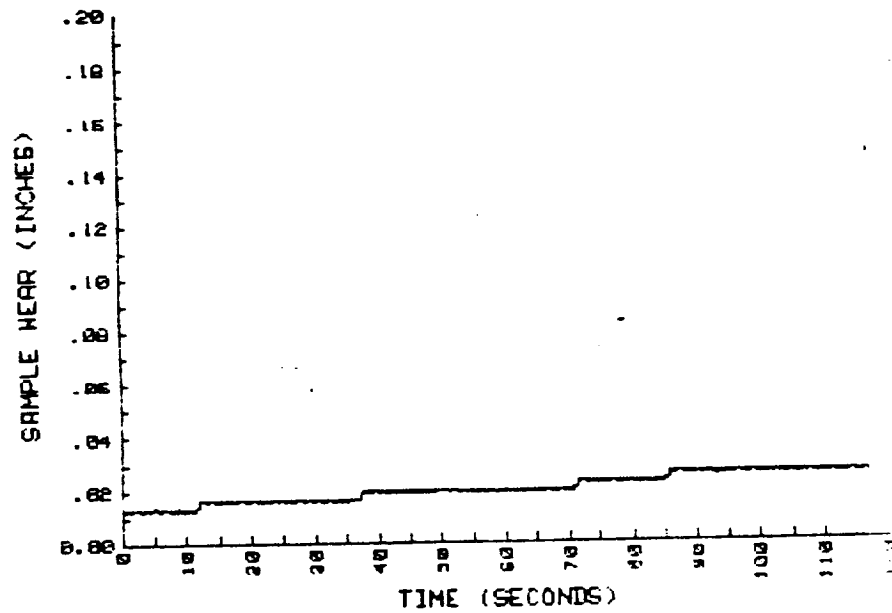
FRT 4246



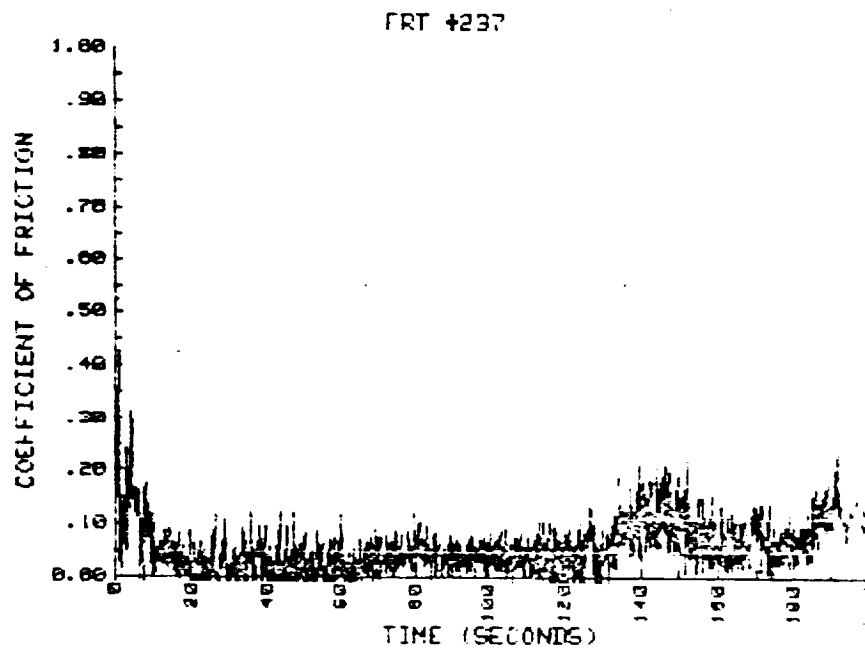
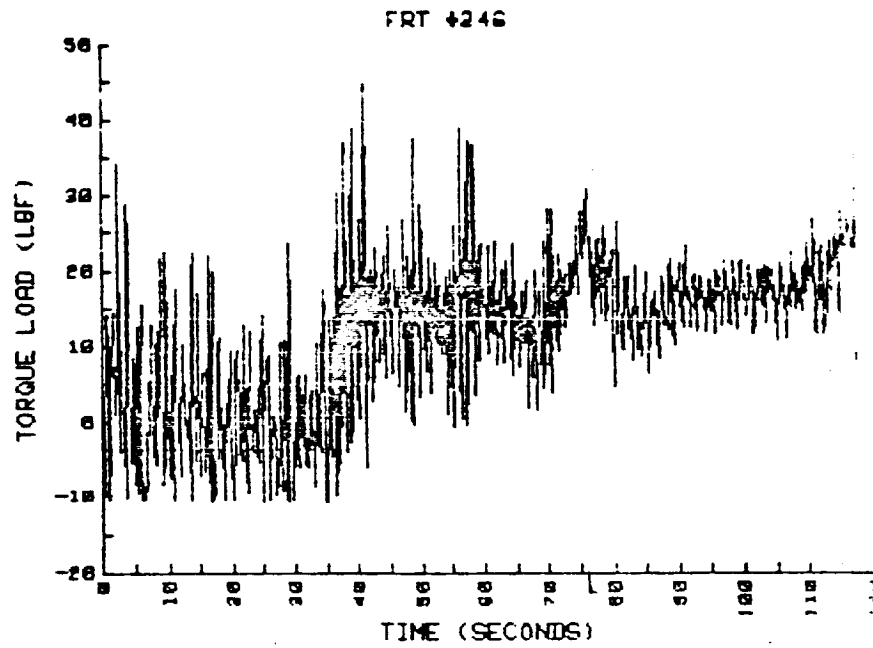
F-46

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FRT 4246

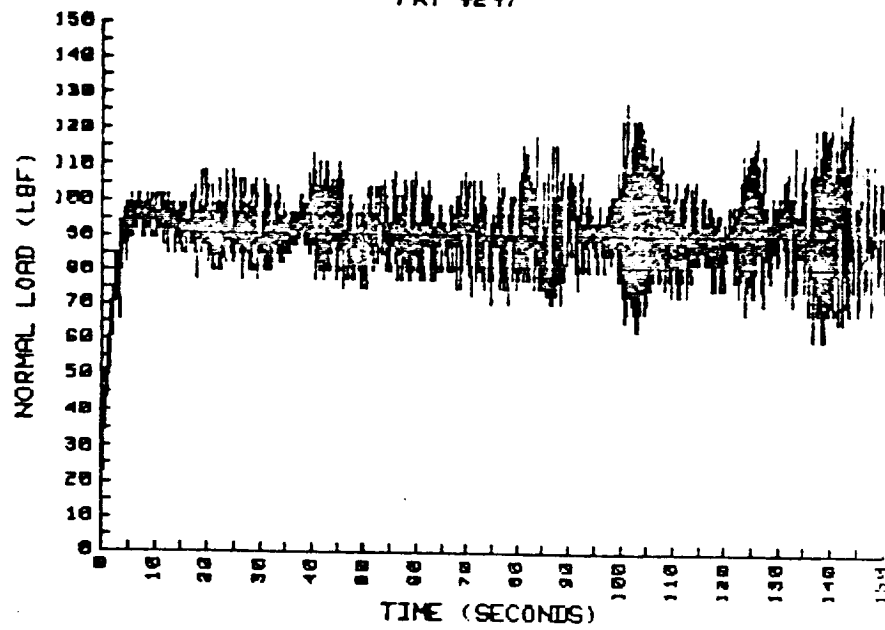


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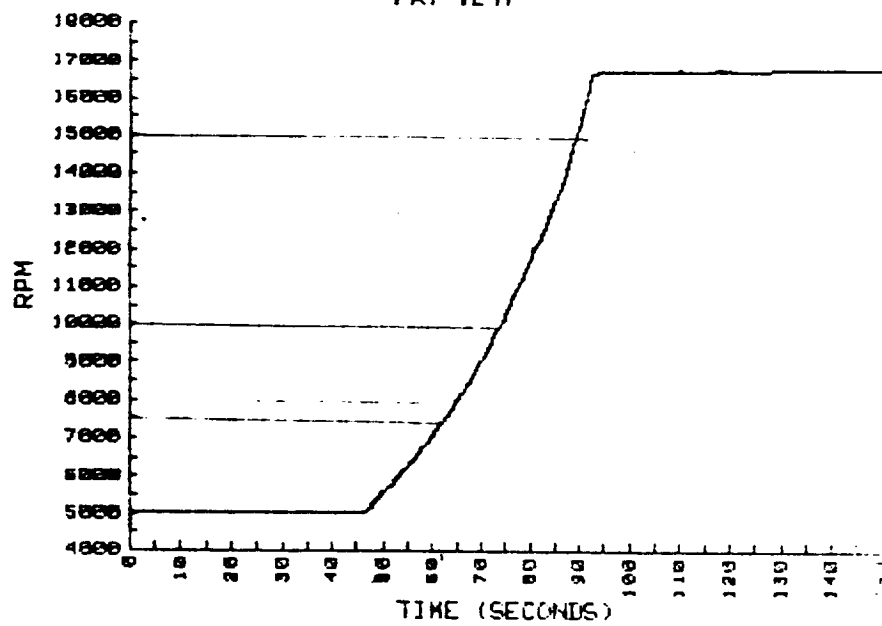


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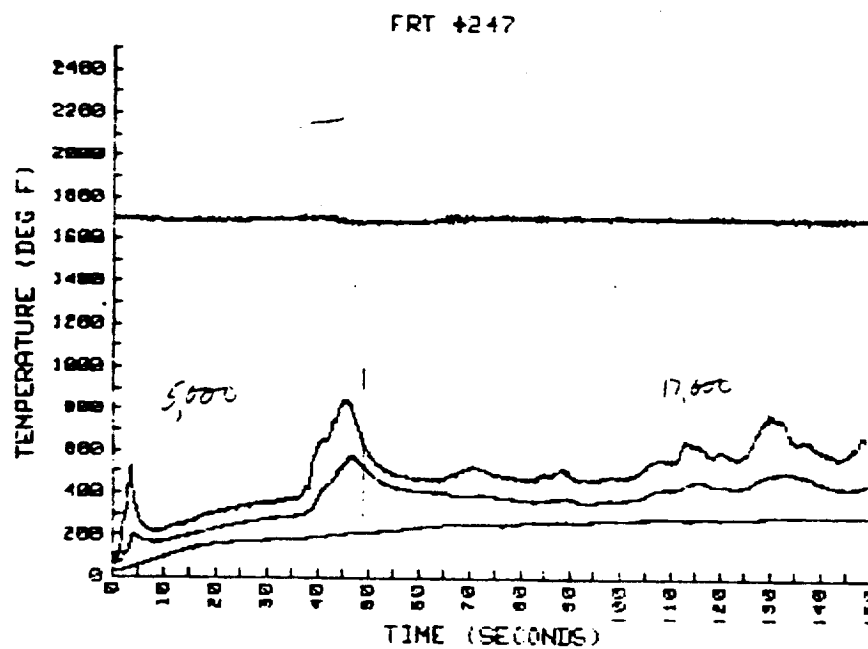
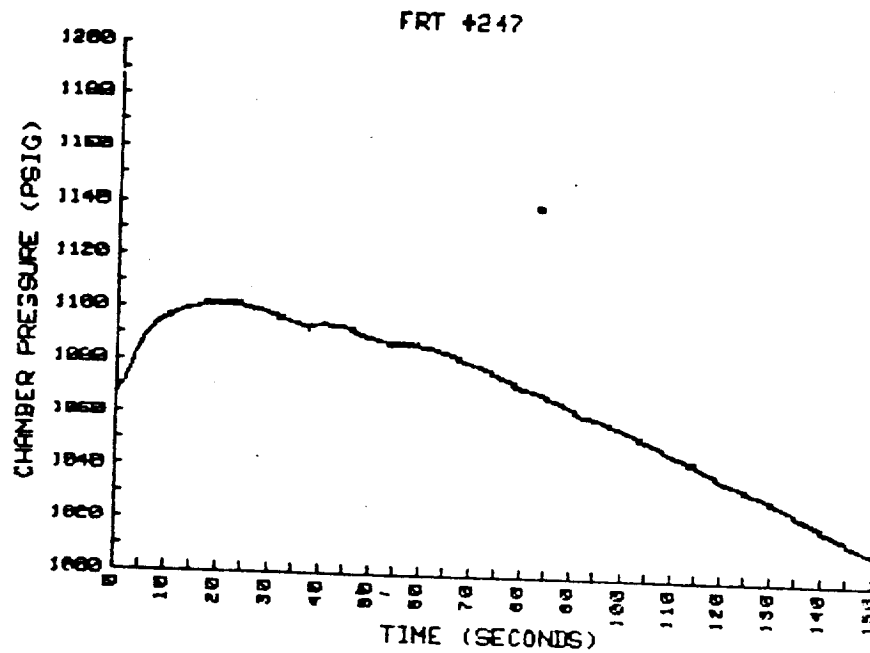
FRT #247



FRT #247

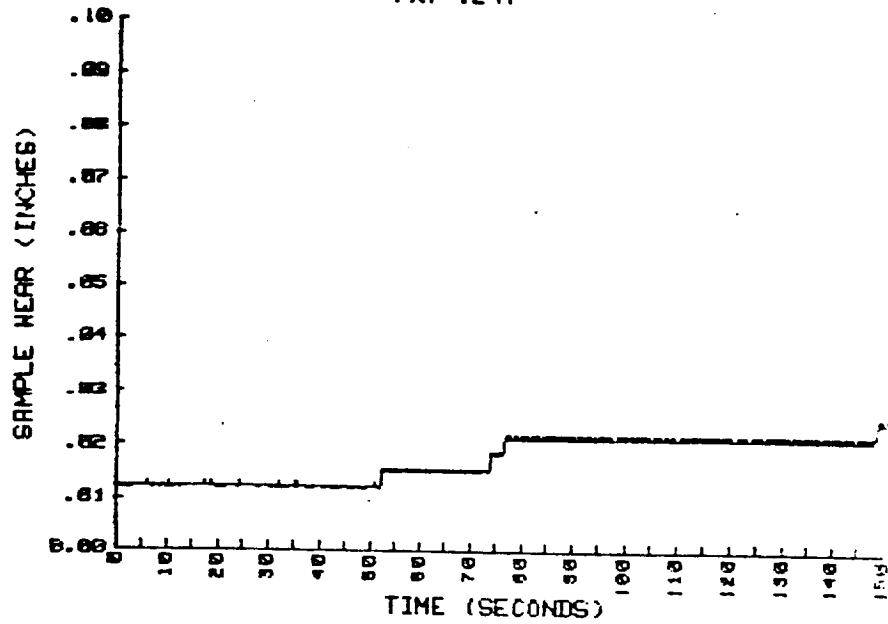


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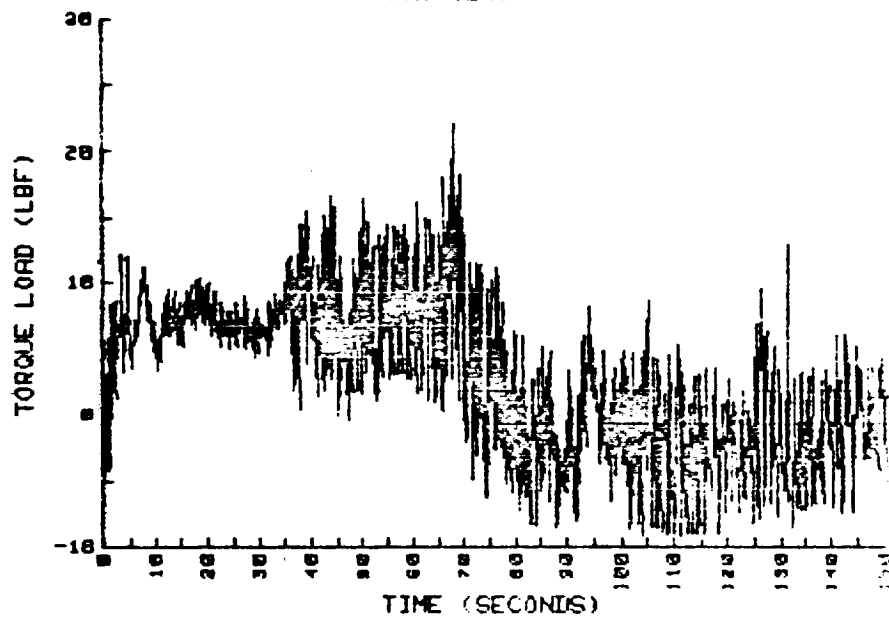


ORIGINAL PAGE IS
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FRT +247

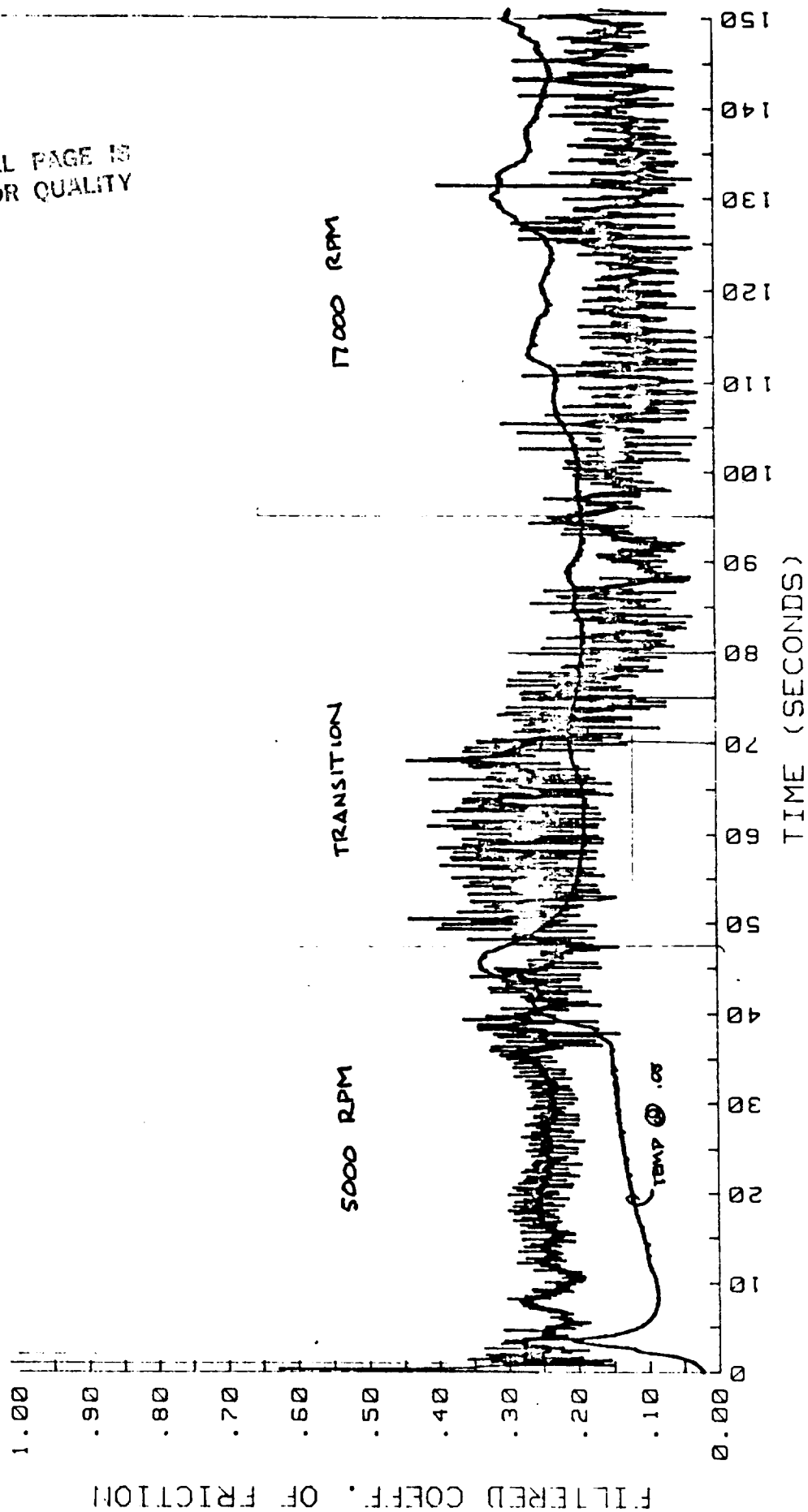


FRT +247



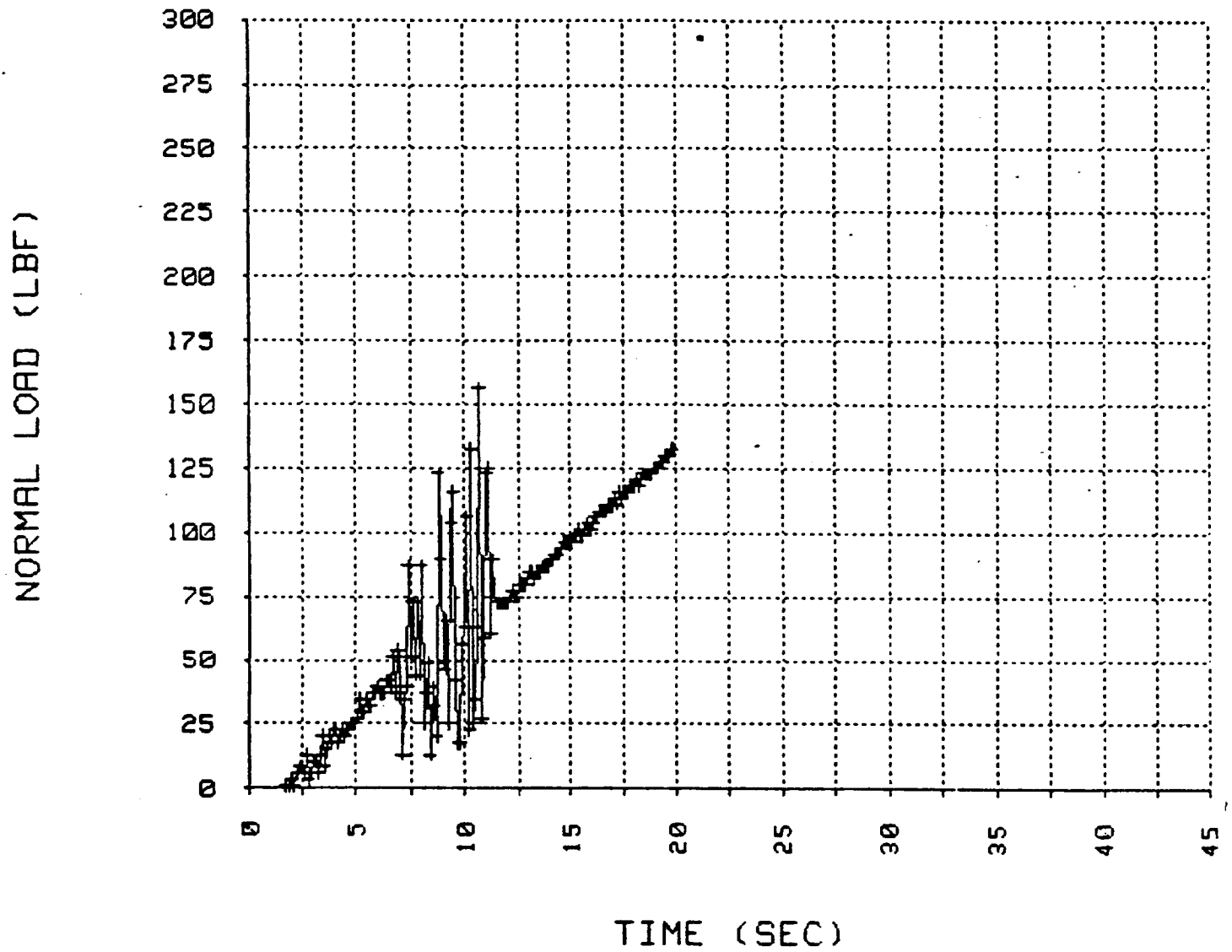
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FRT #247

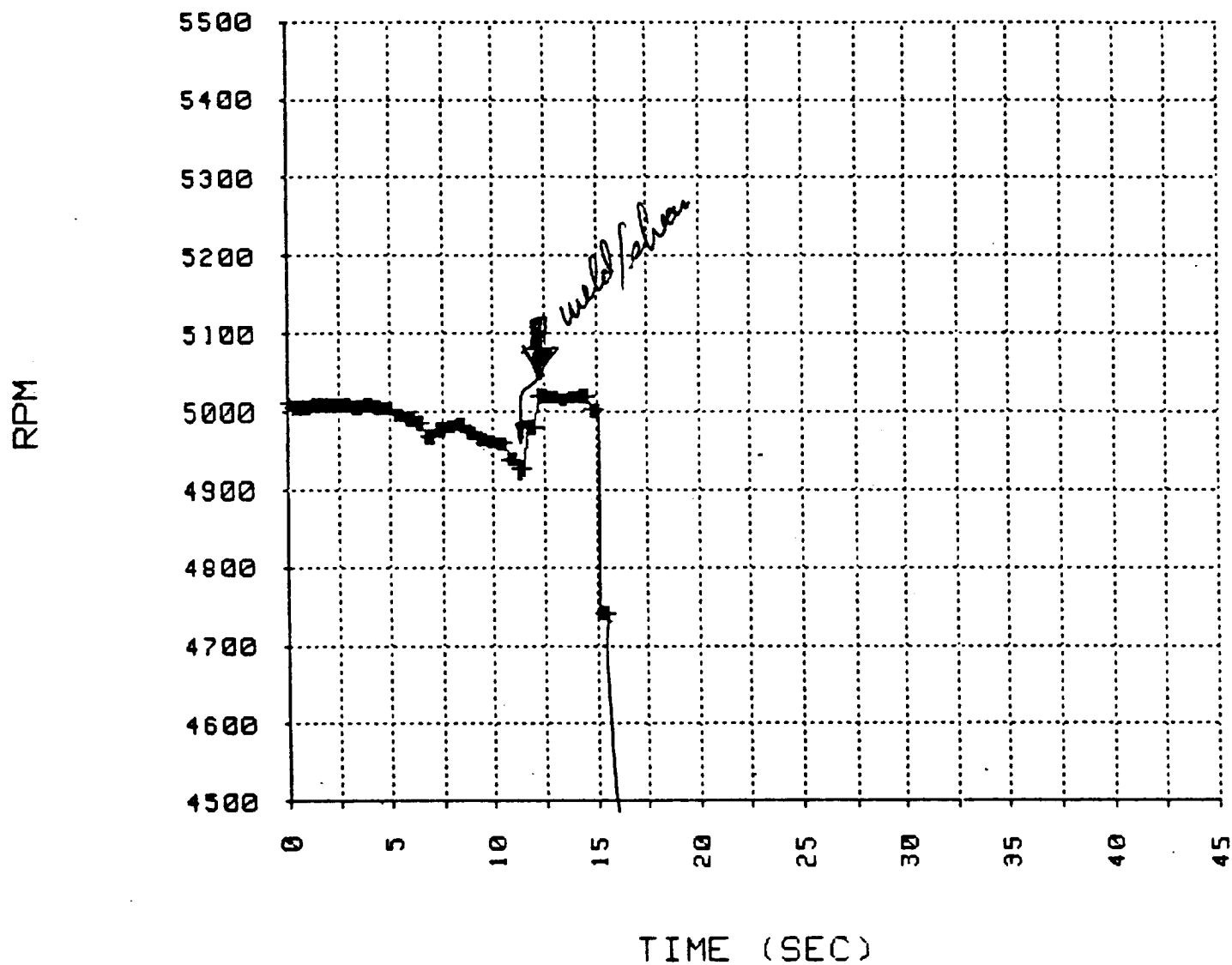


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FRT #216A(100 PSIG GN2)

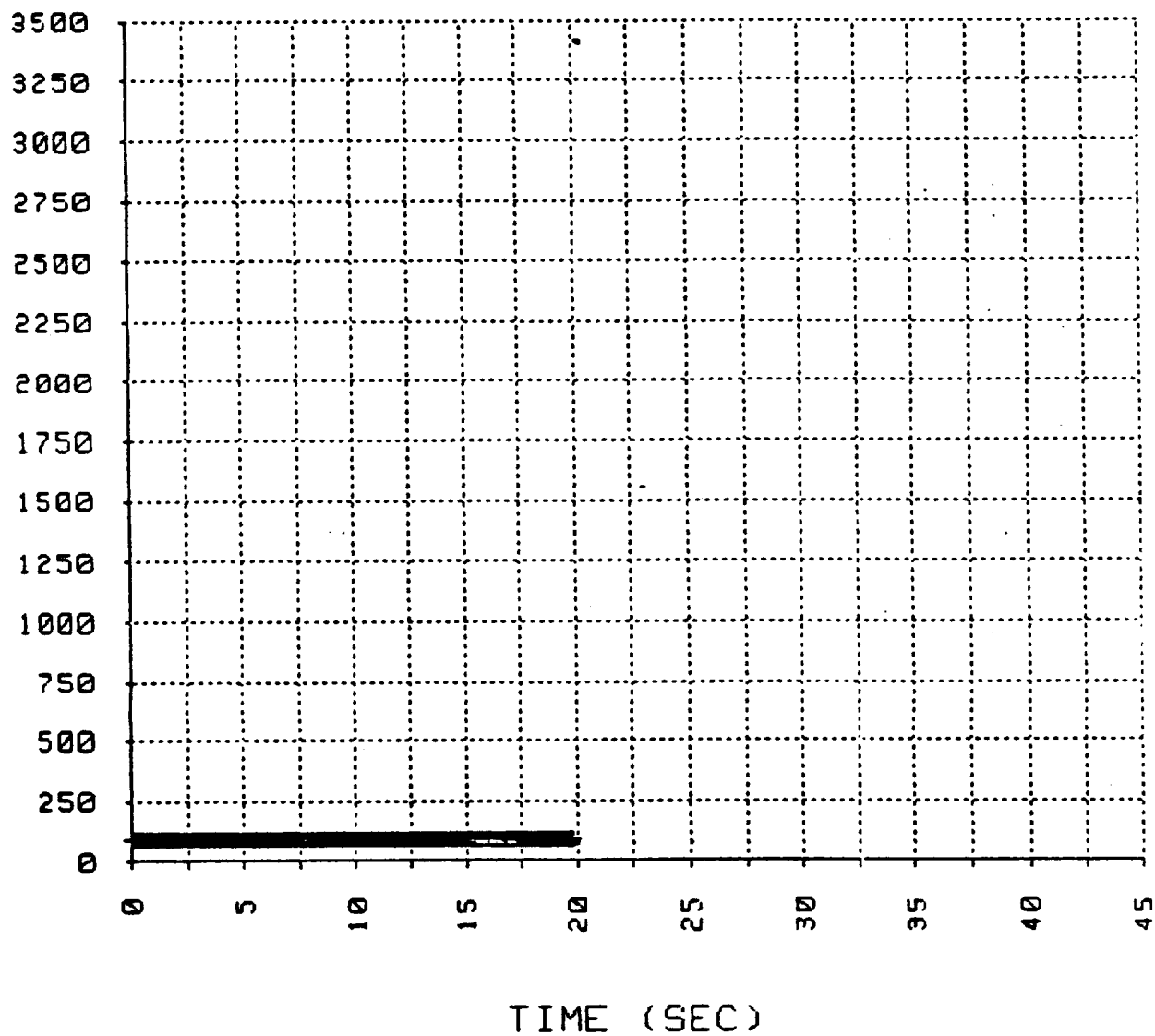


FRT #216A(100 PSIG GN2)



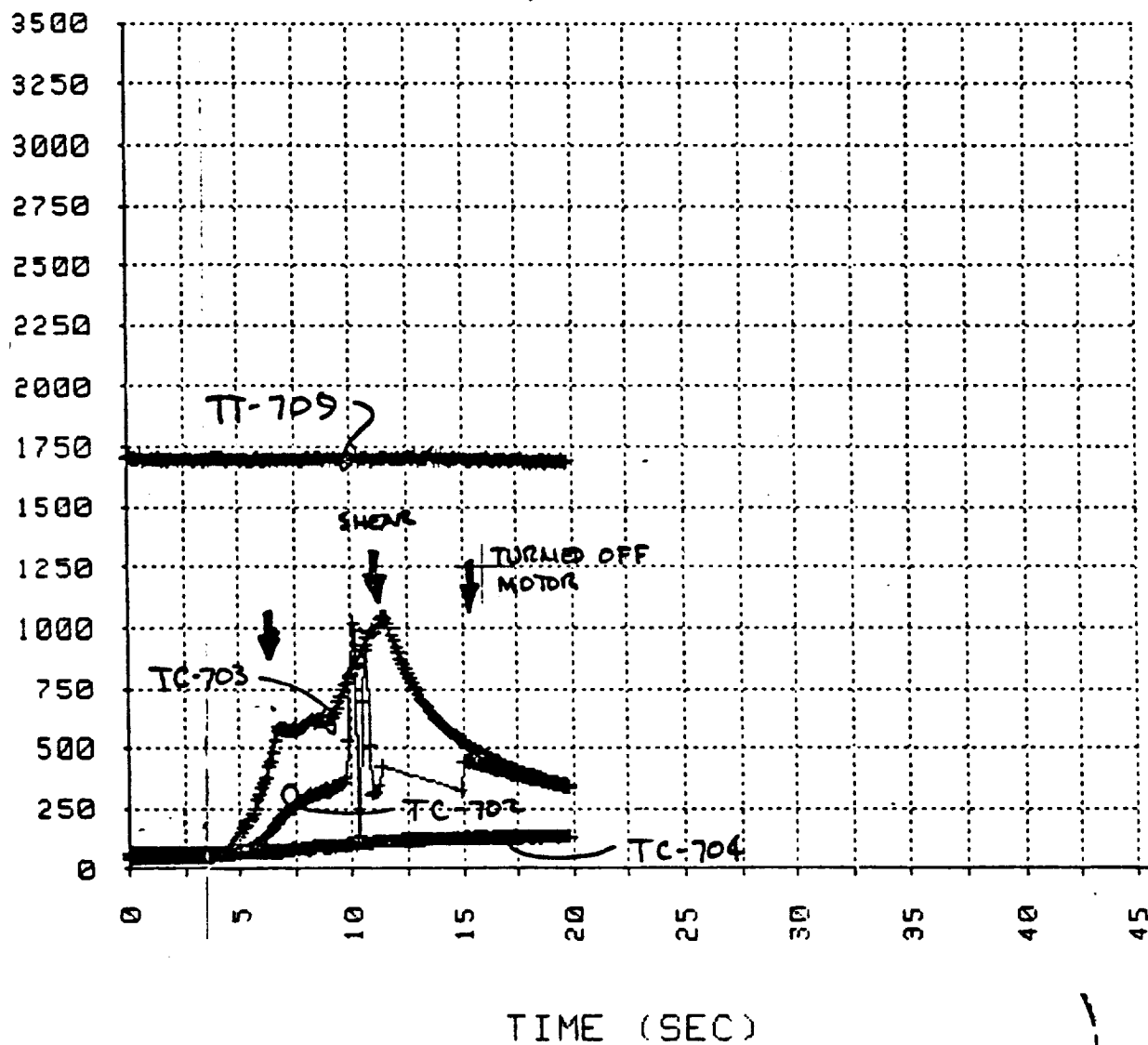
CHAMBER PRESSURE (PSIG)

FRT #216A (100 PSIG GN2)



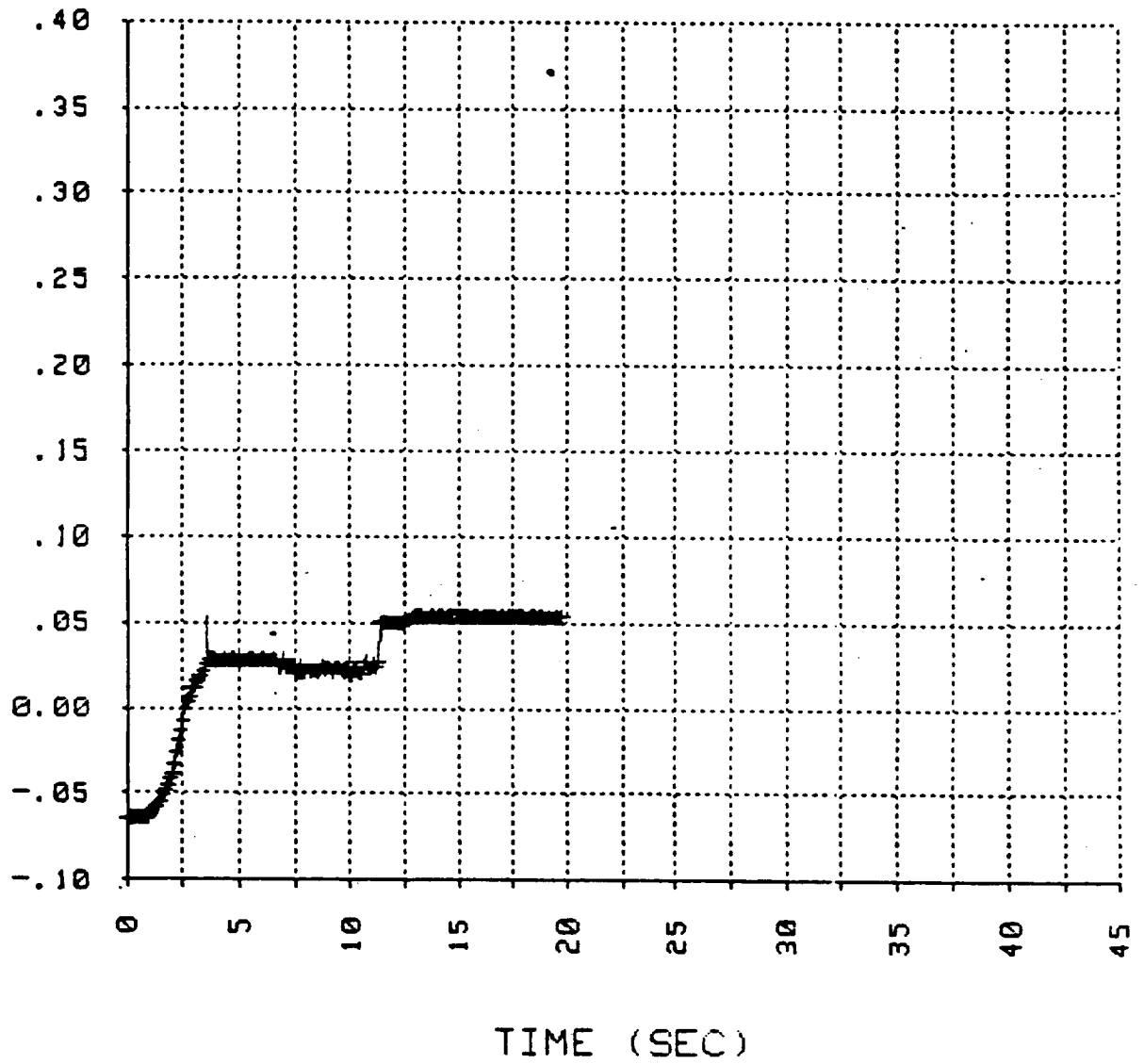
TEMPERATURE (deg F)

FRT #216A(100 PSIG GN2)

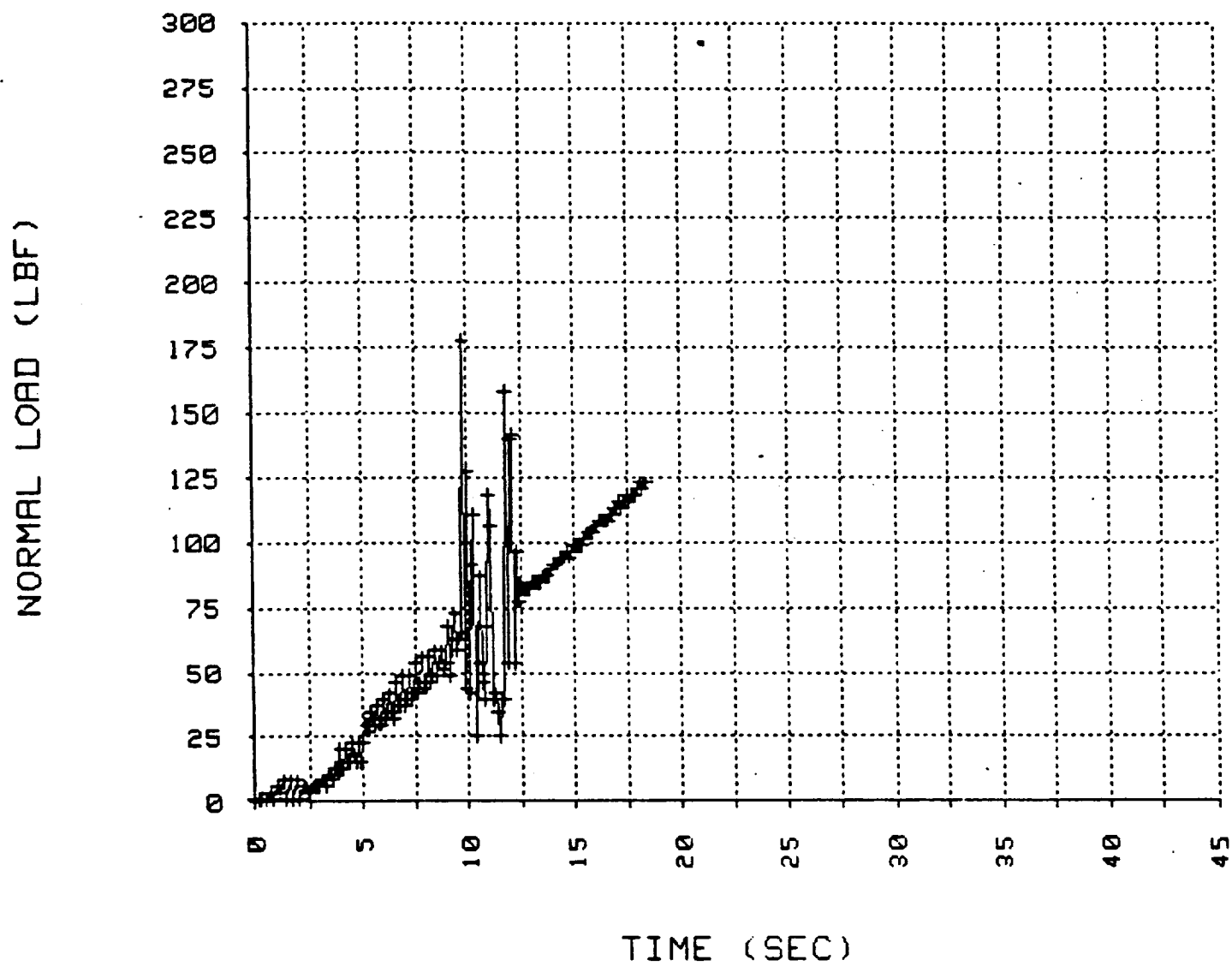


FRT #216A(100 PSIG GN2)

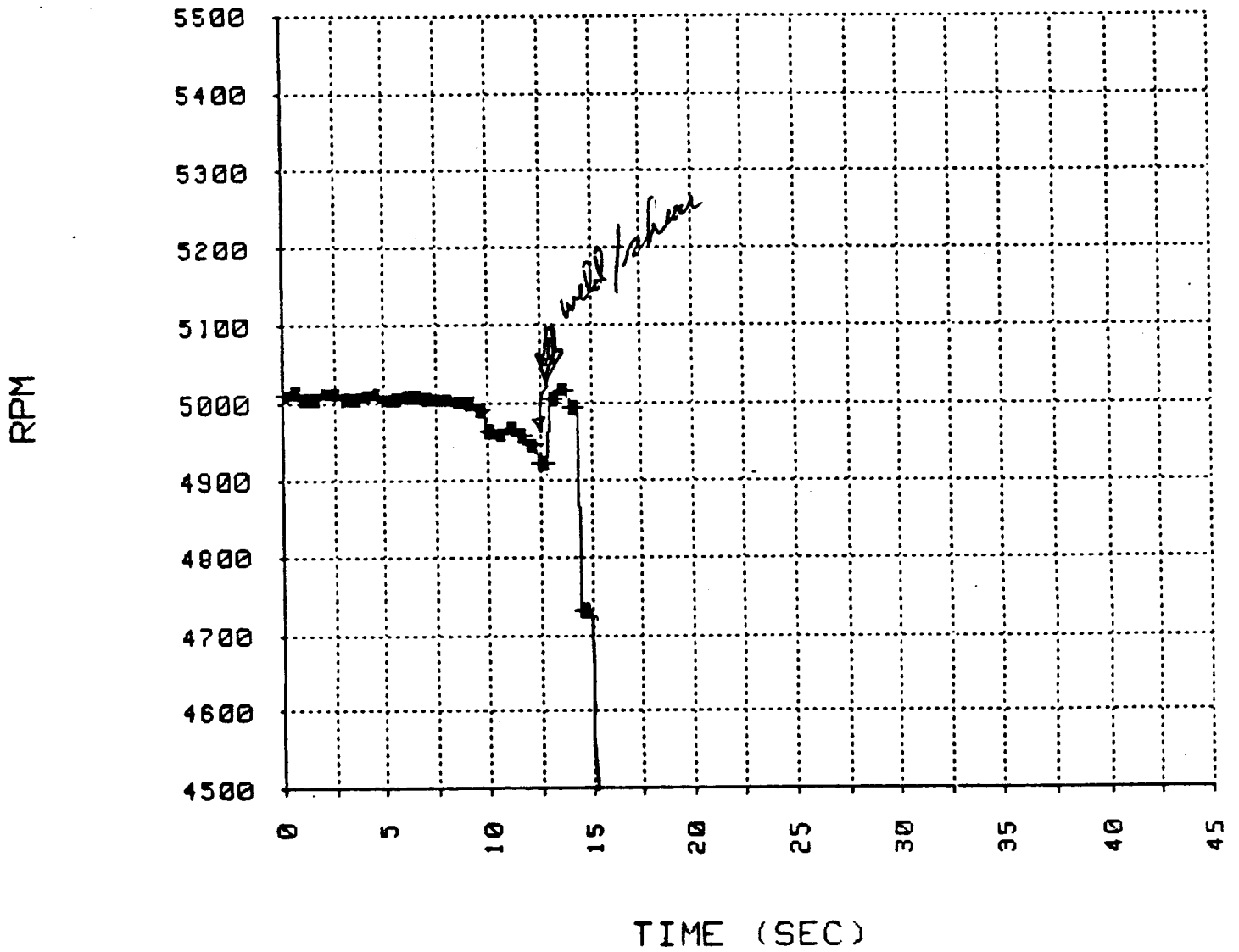
DISPLACEMENT (in)



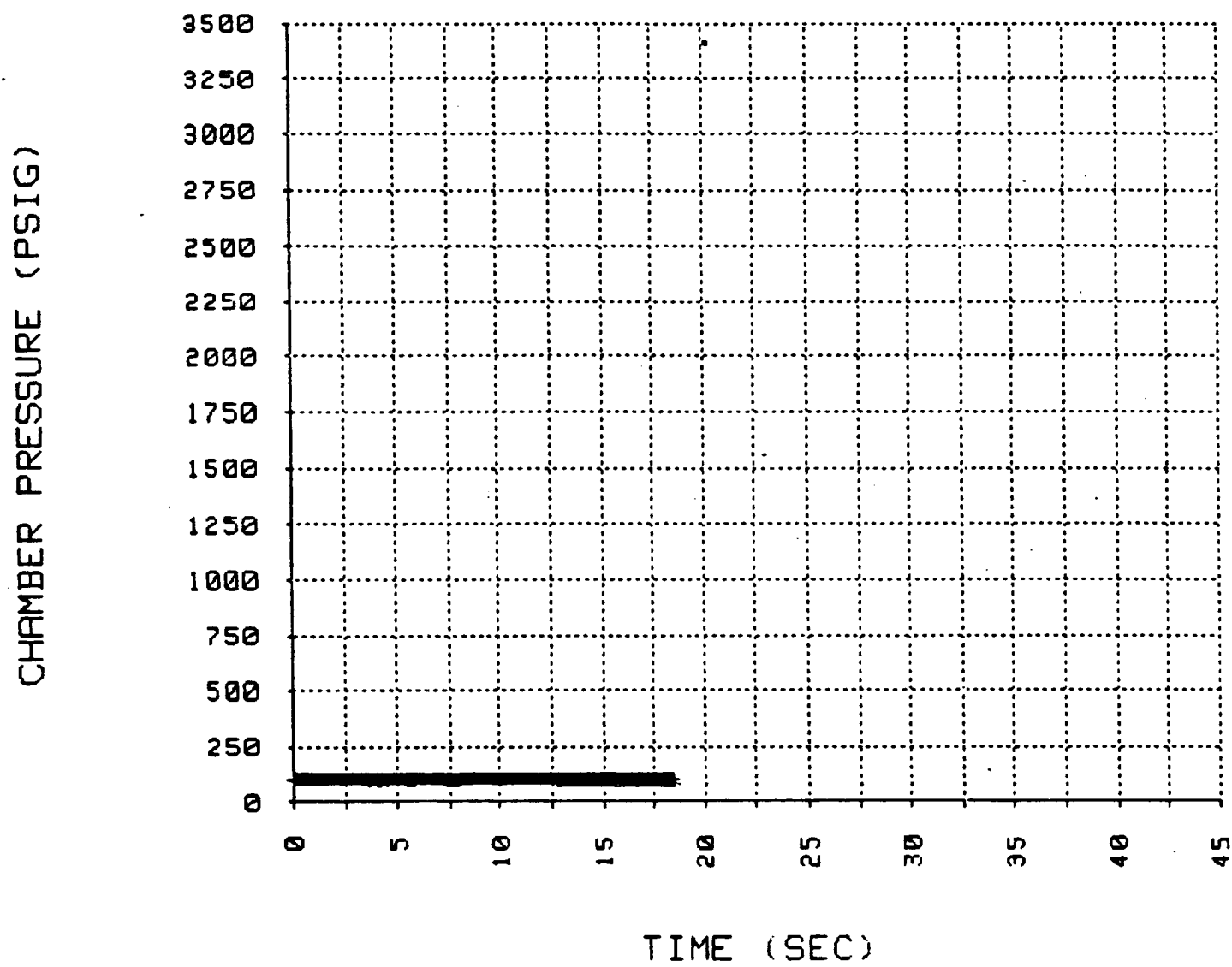
FRT #218 (100 PSIG GN2)



FRT #218 (100 PSIG GN2)

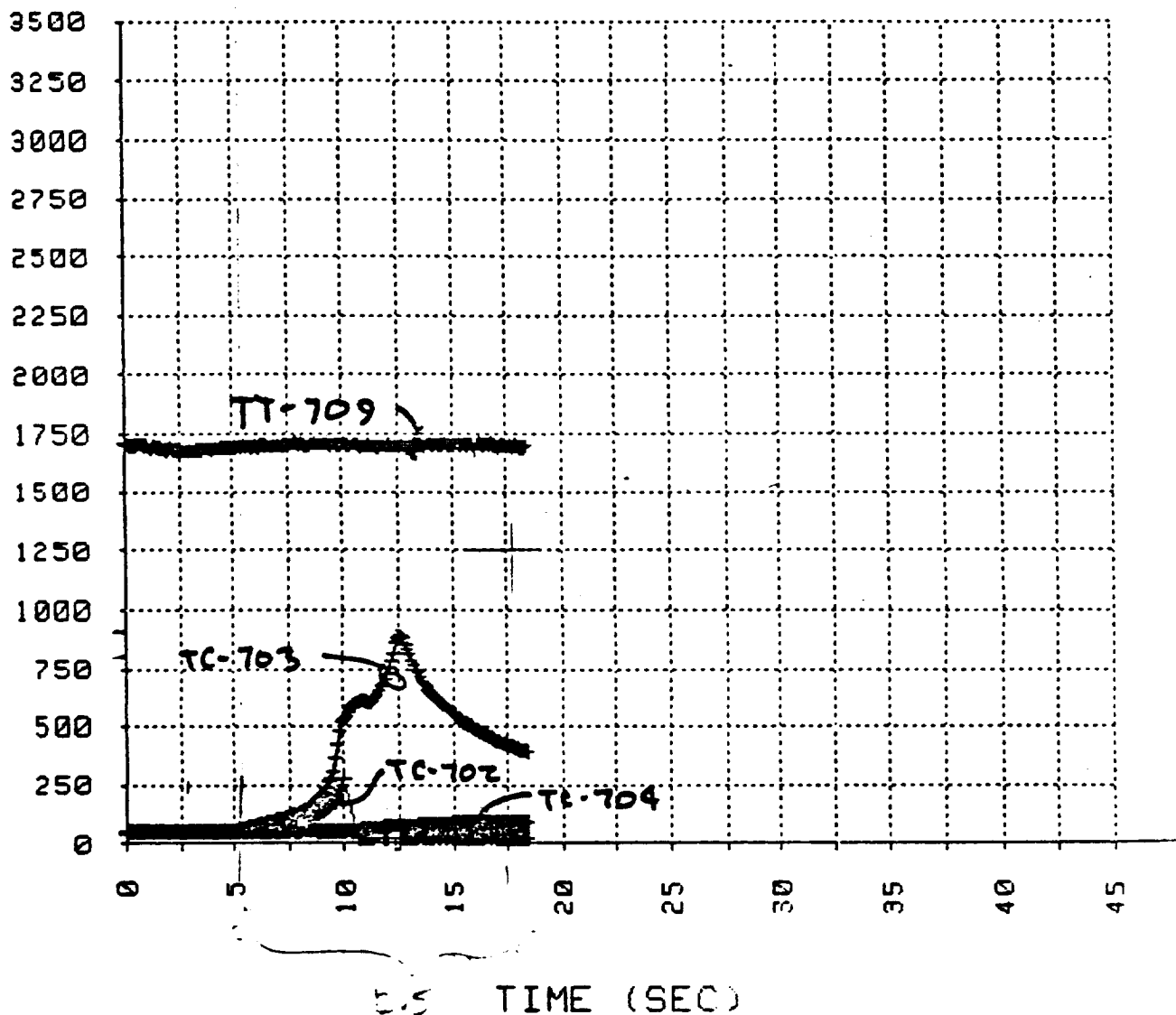


FRT #218 (100 PSIG GN2)



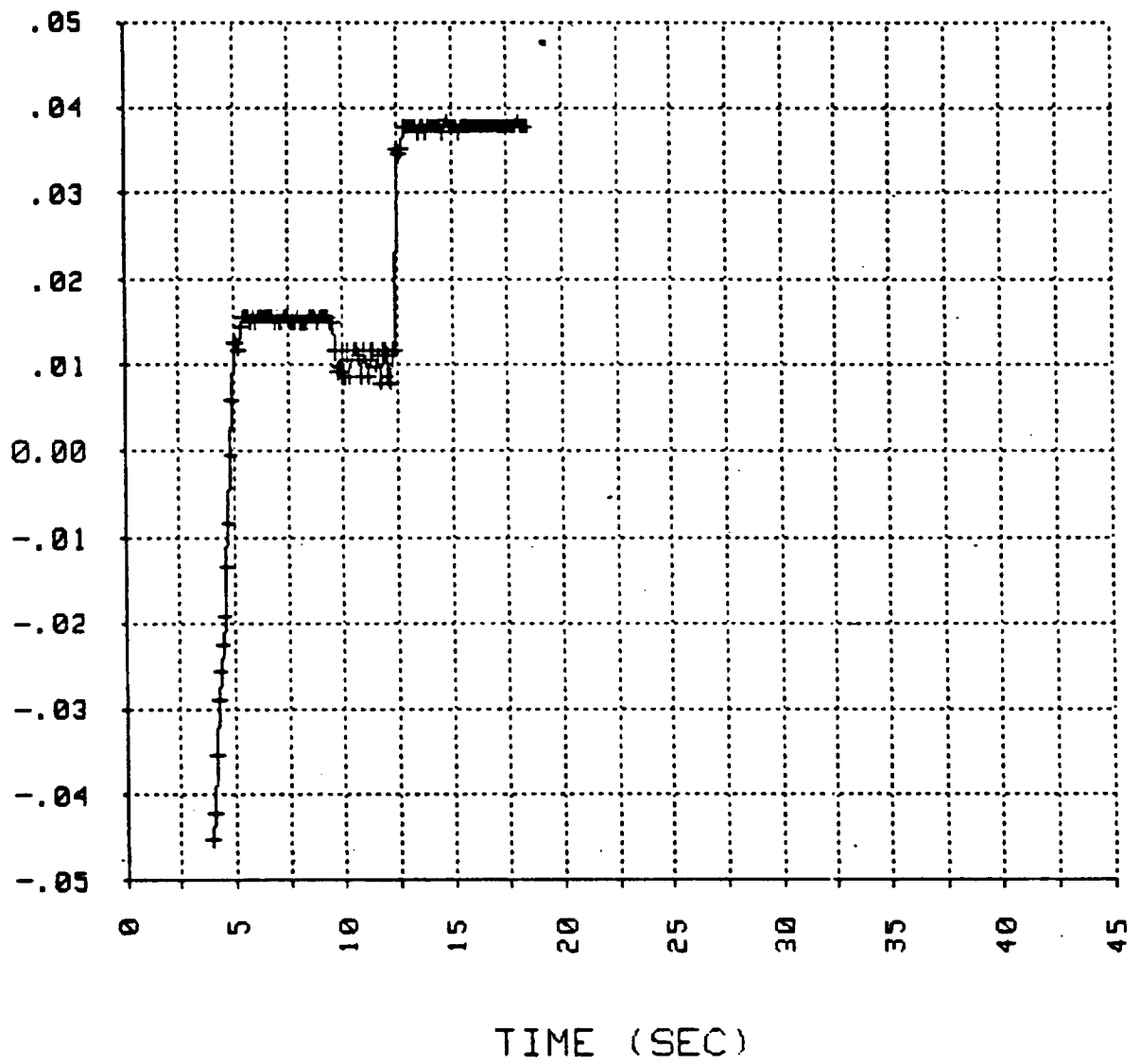
TEMPERATURE (deg F)

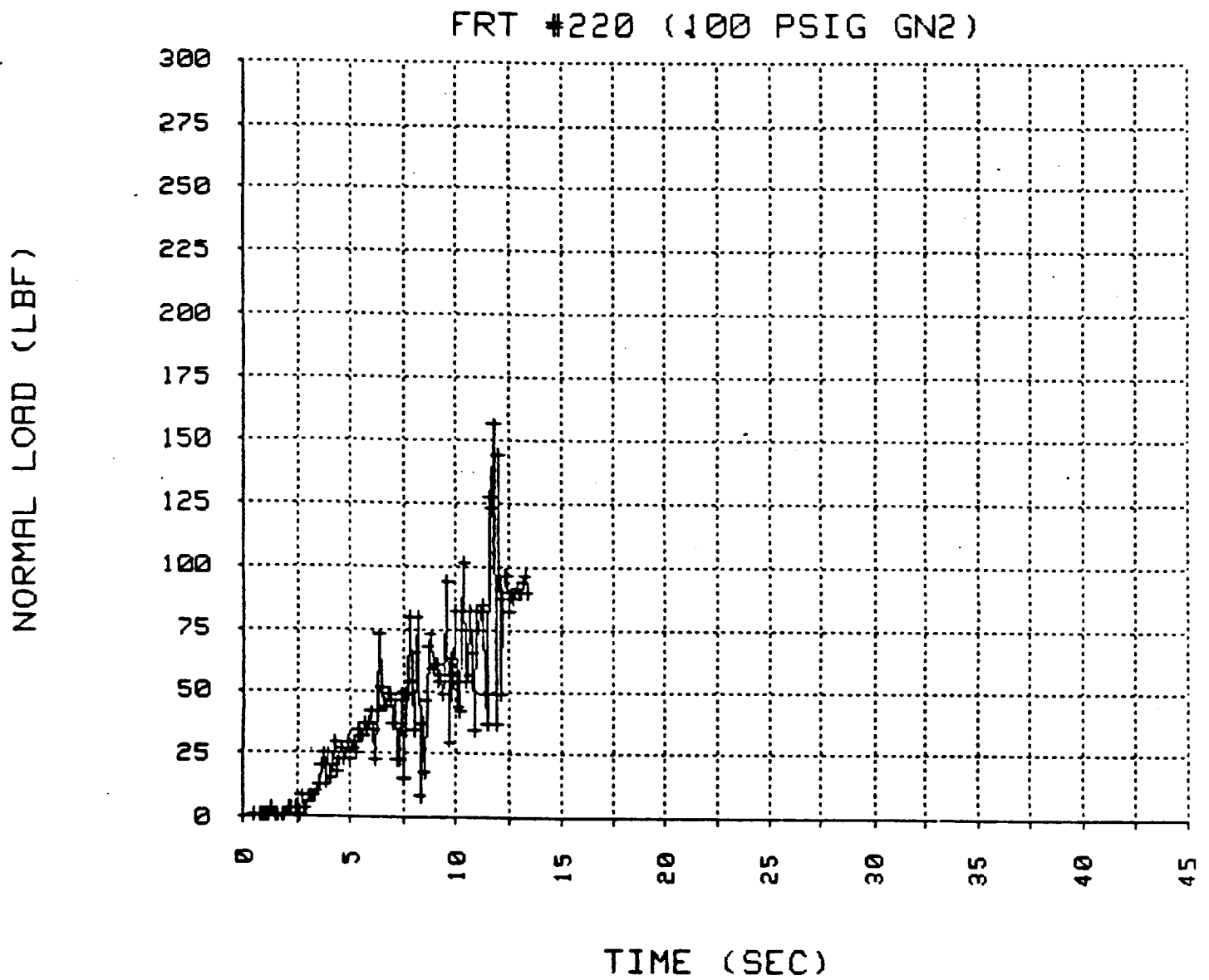
FRT #218 (100 PSIG GN2)



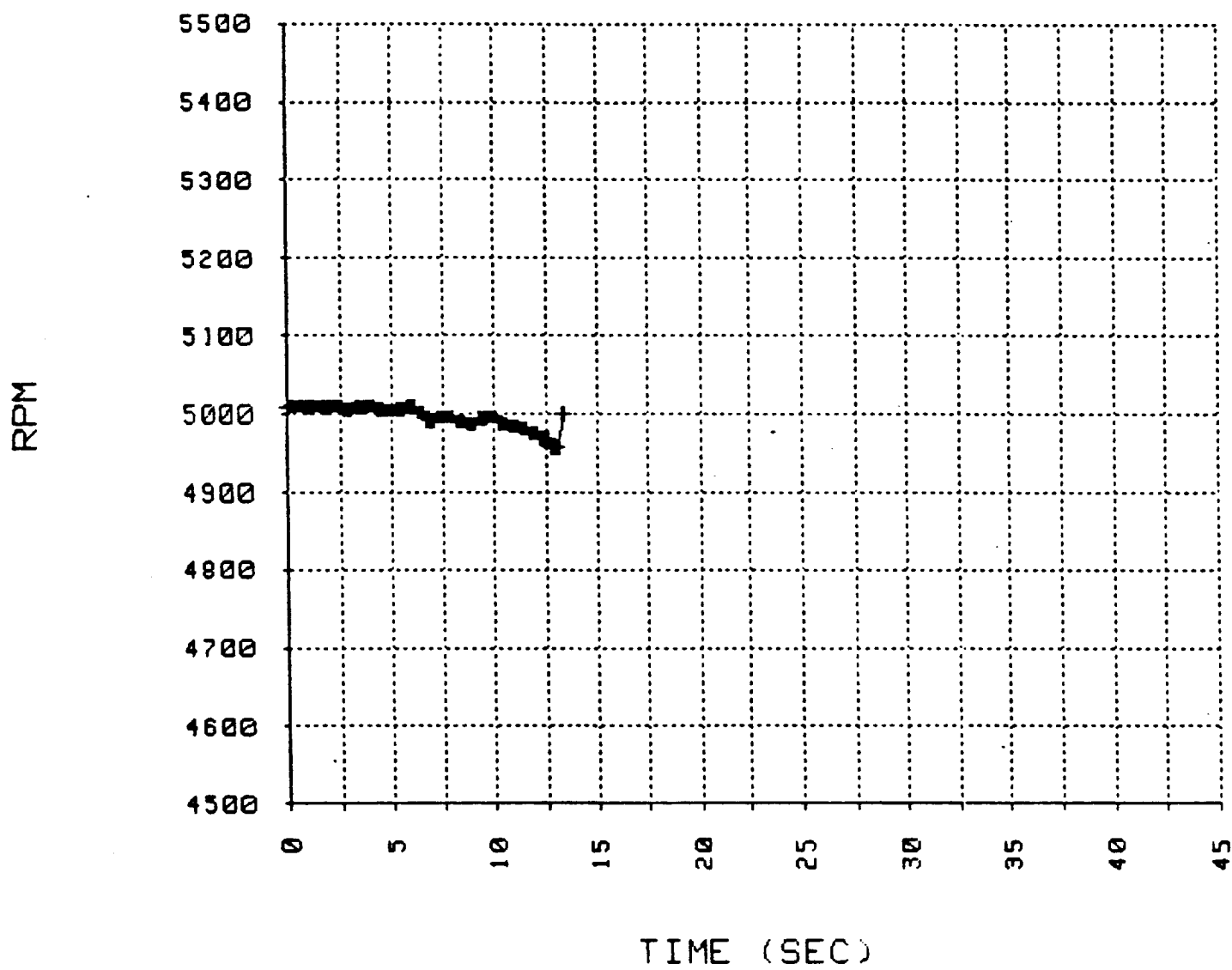
DISPLACEMENT (in)

FRT #210 (100 PSIG GN2)



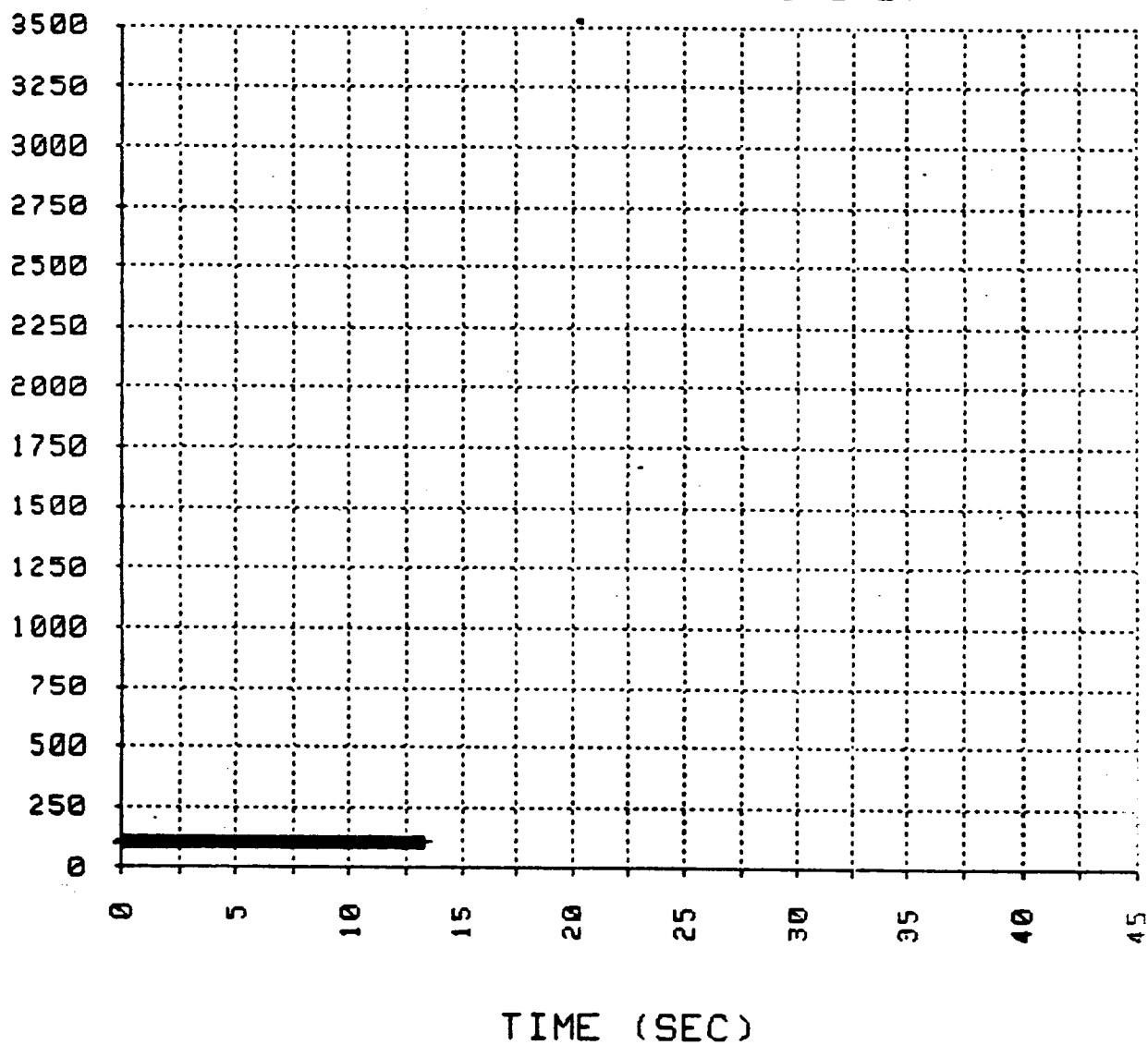


FRT #220 (100 PSIG GN2)



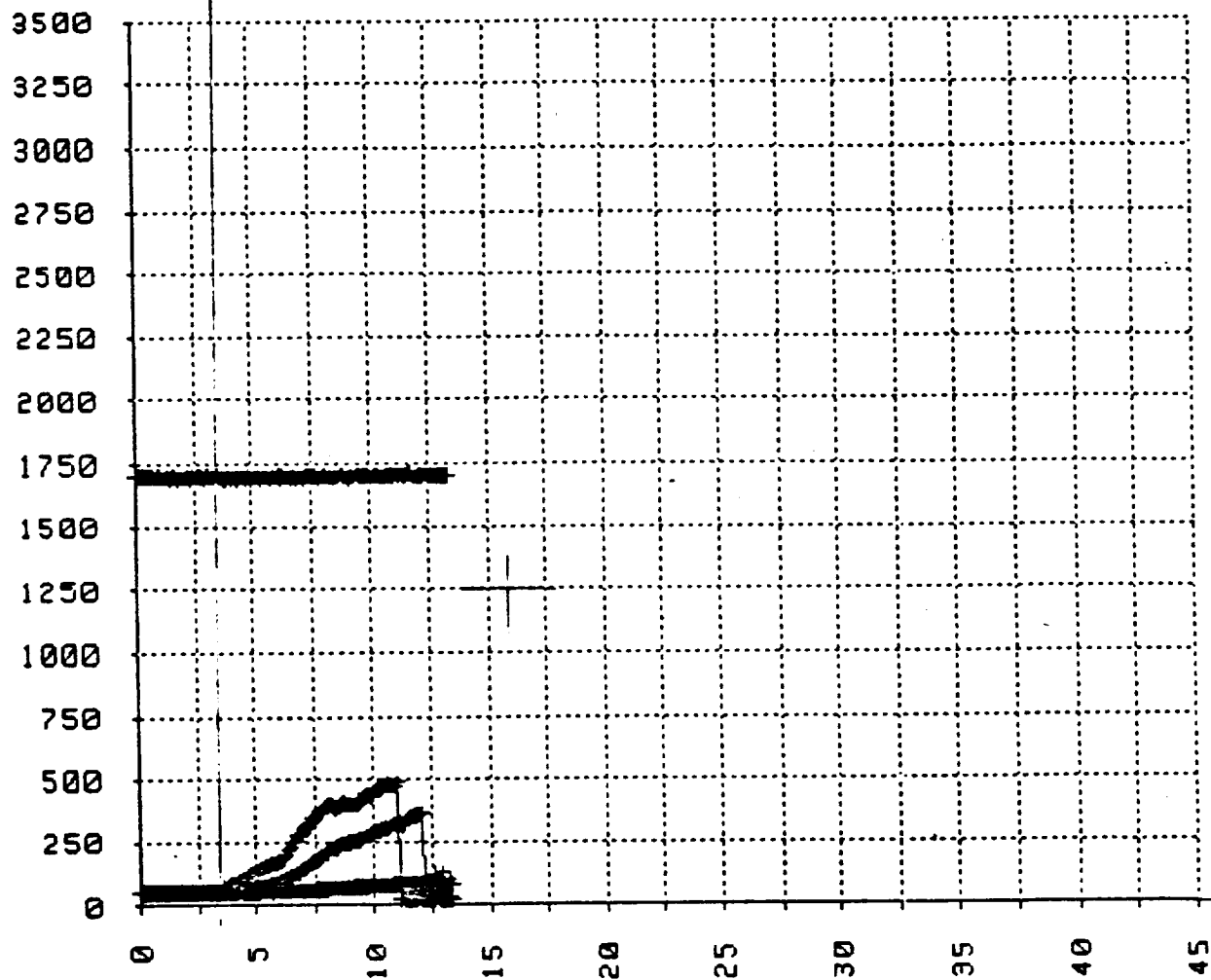
CHAMBER PRESSURE (PSIG)

FRT #220 (100 PSIG GN2)



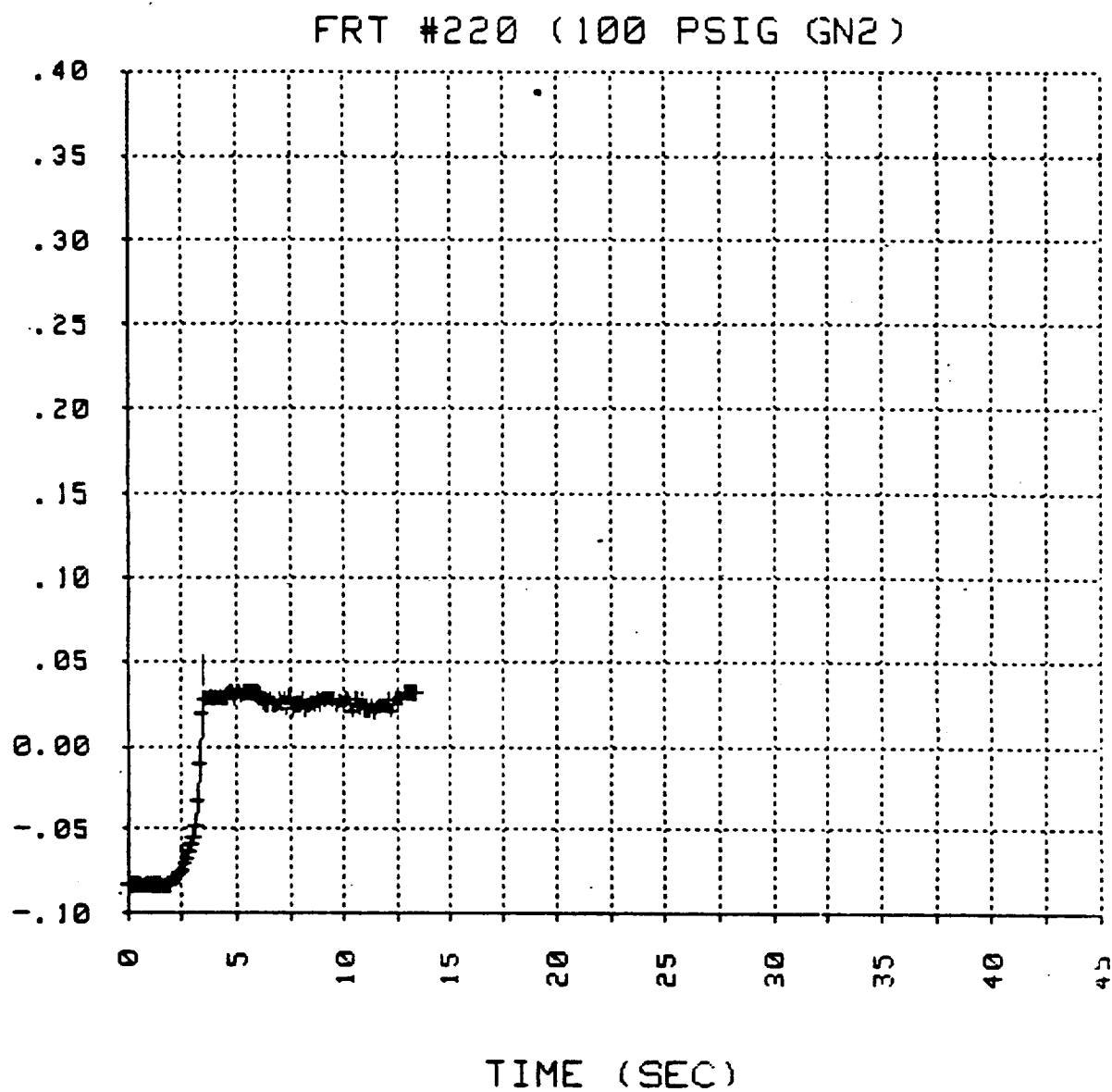
TEMPERATURE (deg F)

FRT #220 (100 PSIG GN2)

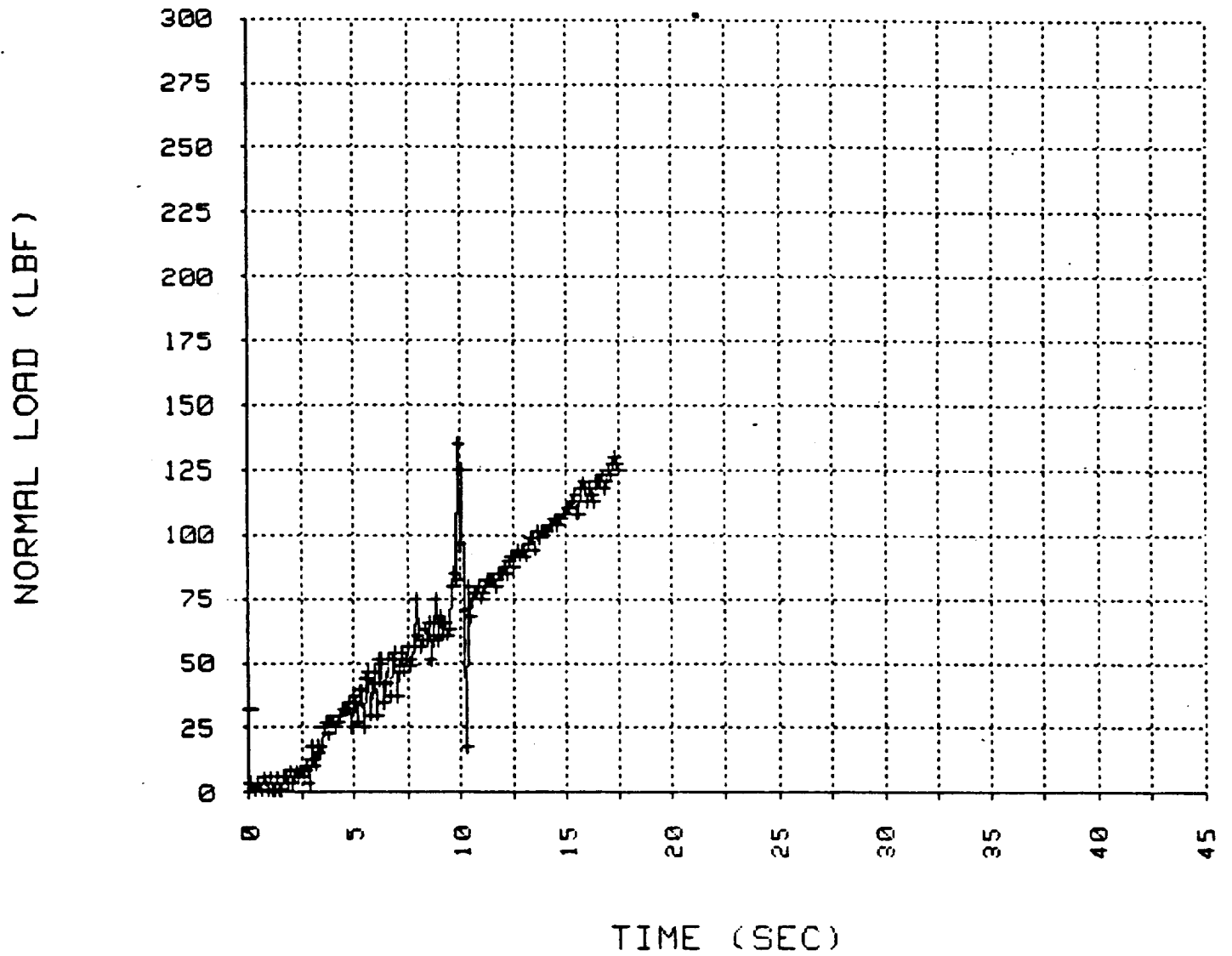


TIME (SEC)

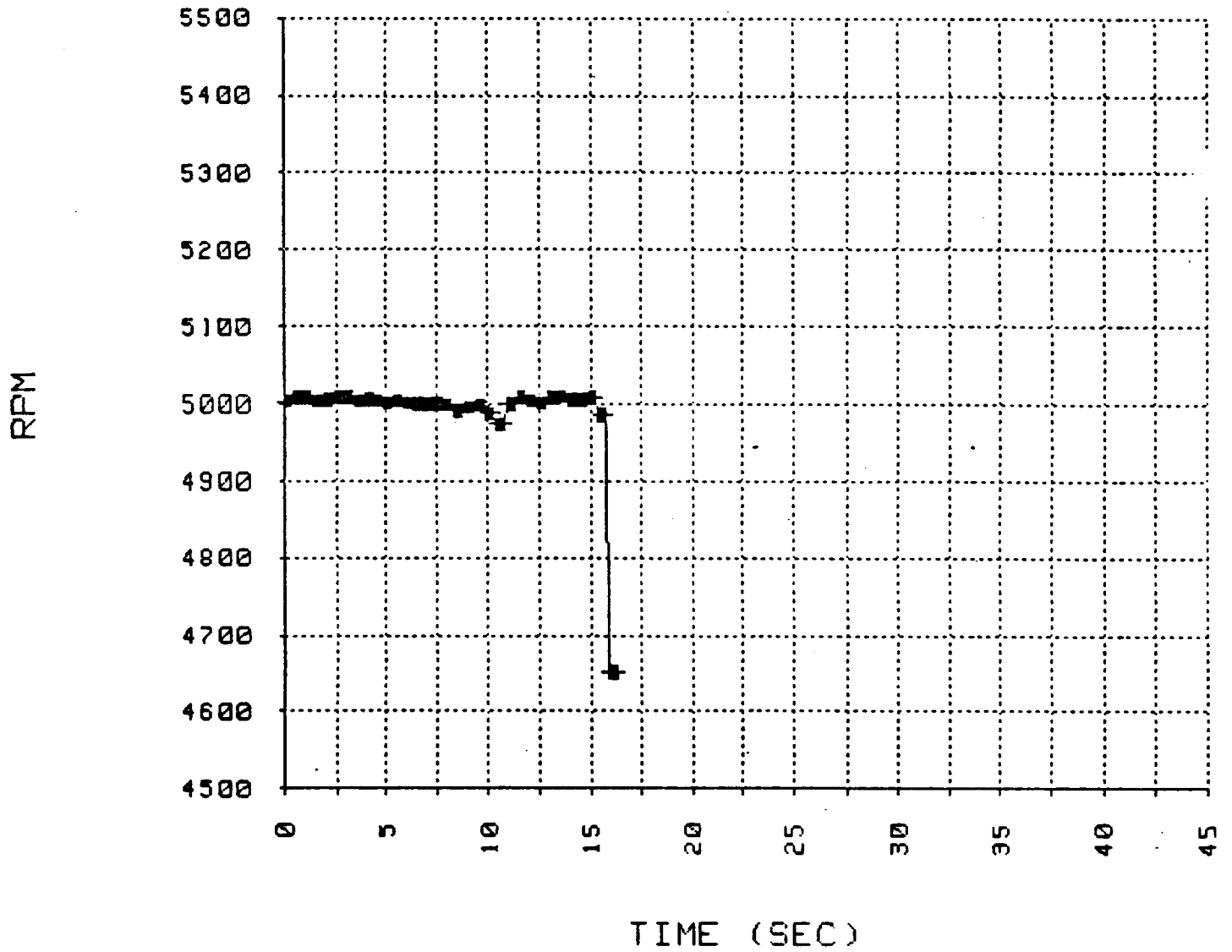
DISPLACEMENT (in)



FRT #222 (100 PSIG GN2)

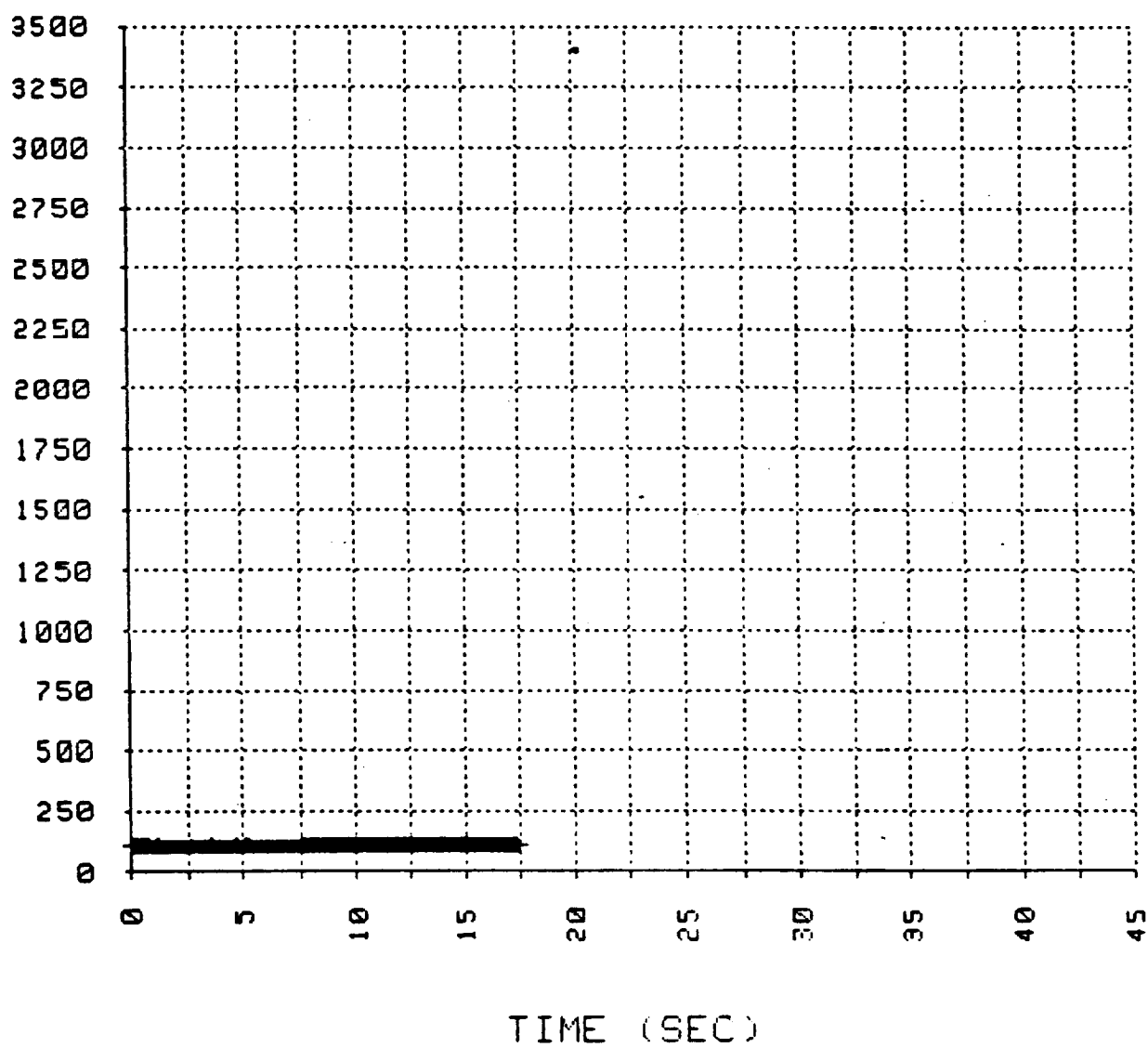


FRT #222 (100 PSIG GN2)



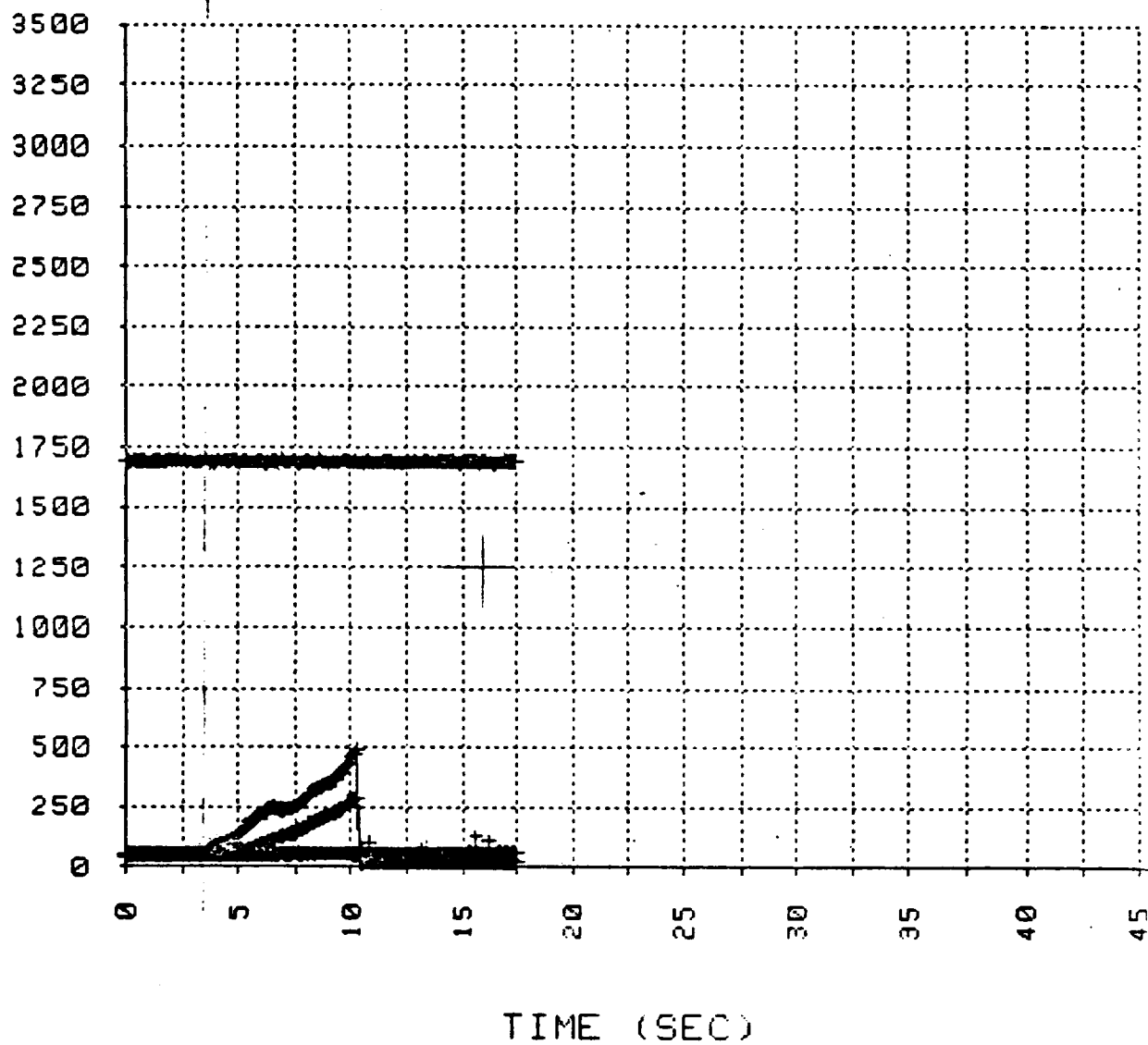
CHAMBER PRESSURE (PSIG)

FRT #222 (100 PSIG GN2)

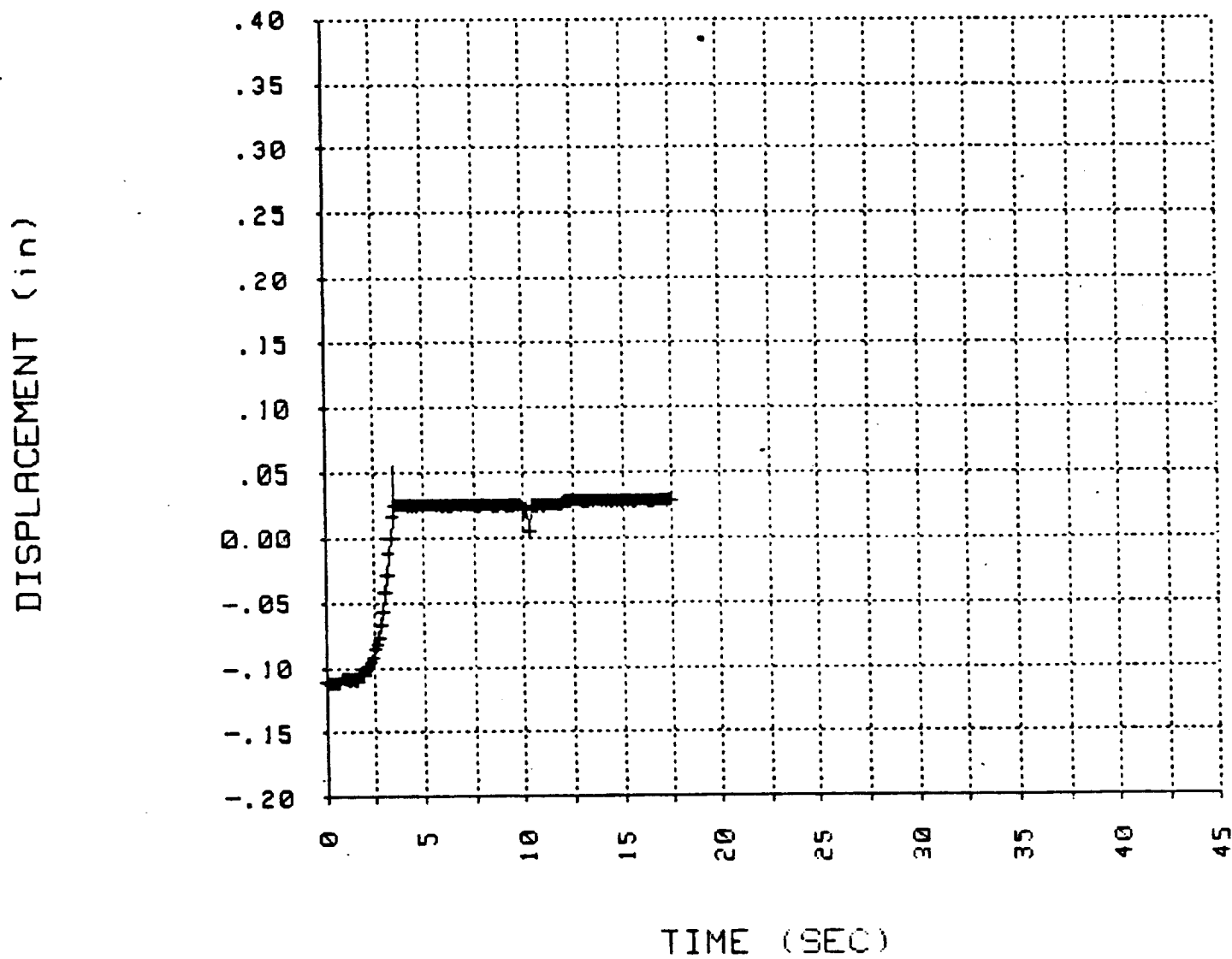


TEMPERATURE (deg F)

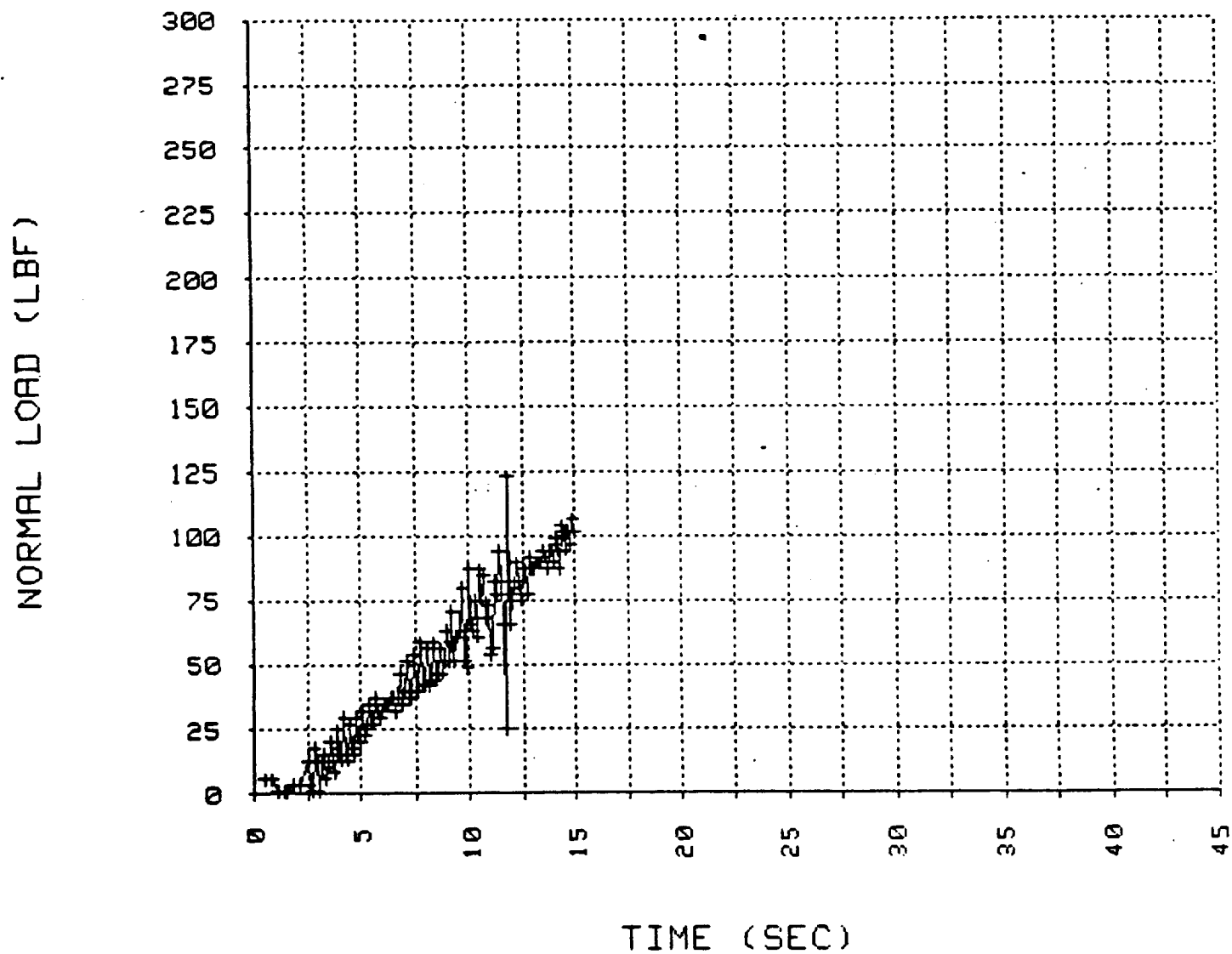
FRT #222 (100 PSIG GN2)



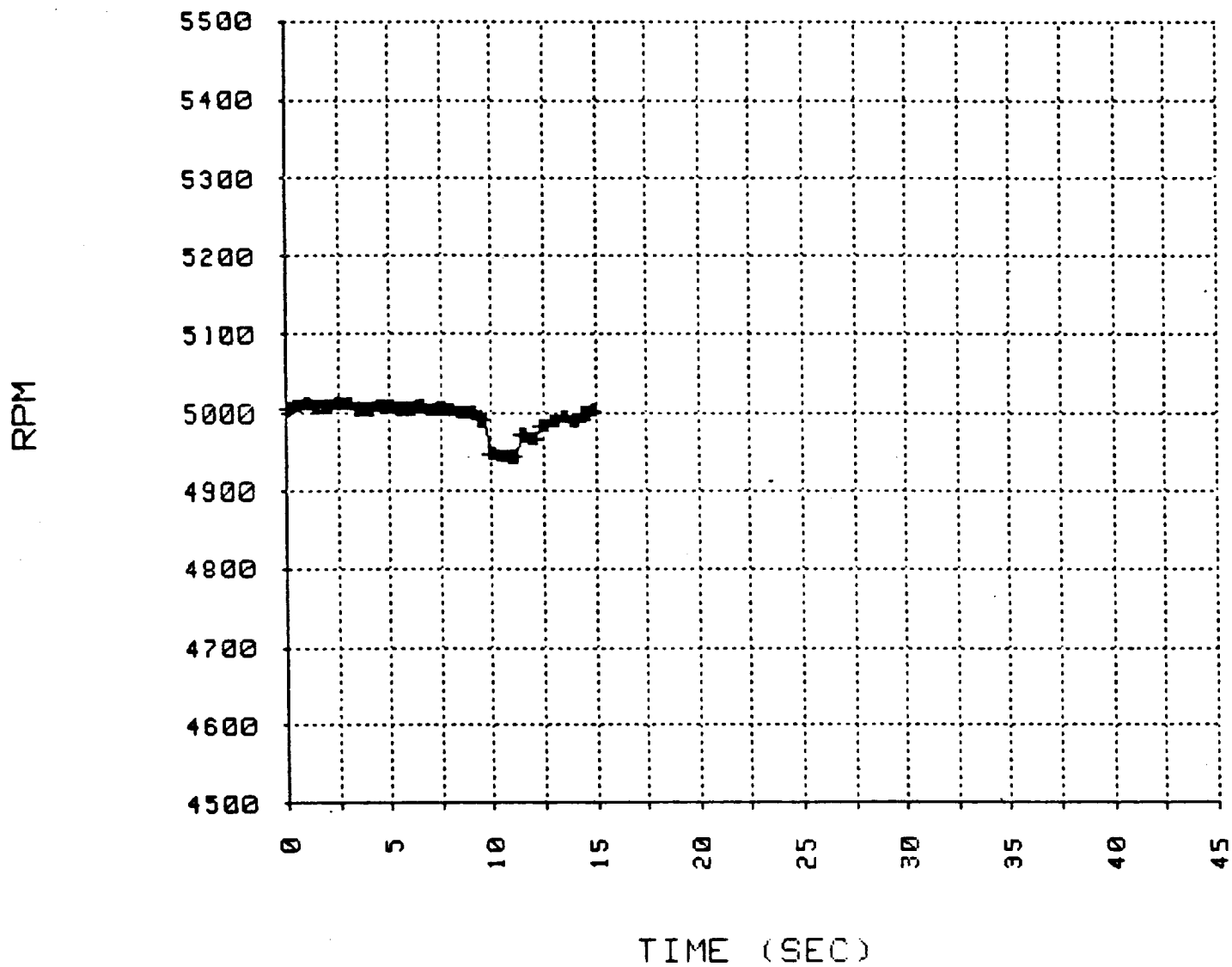
FRT #222 (100 PSIG GN2)



FRT #223 (100 PSIG GN2)

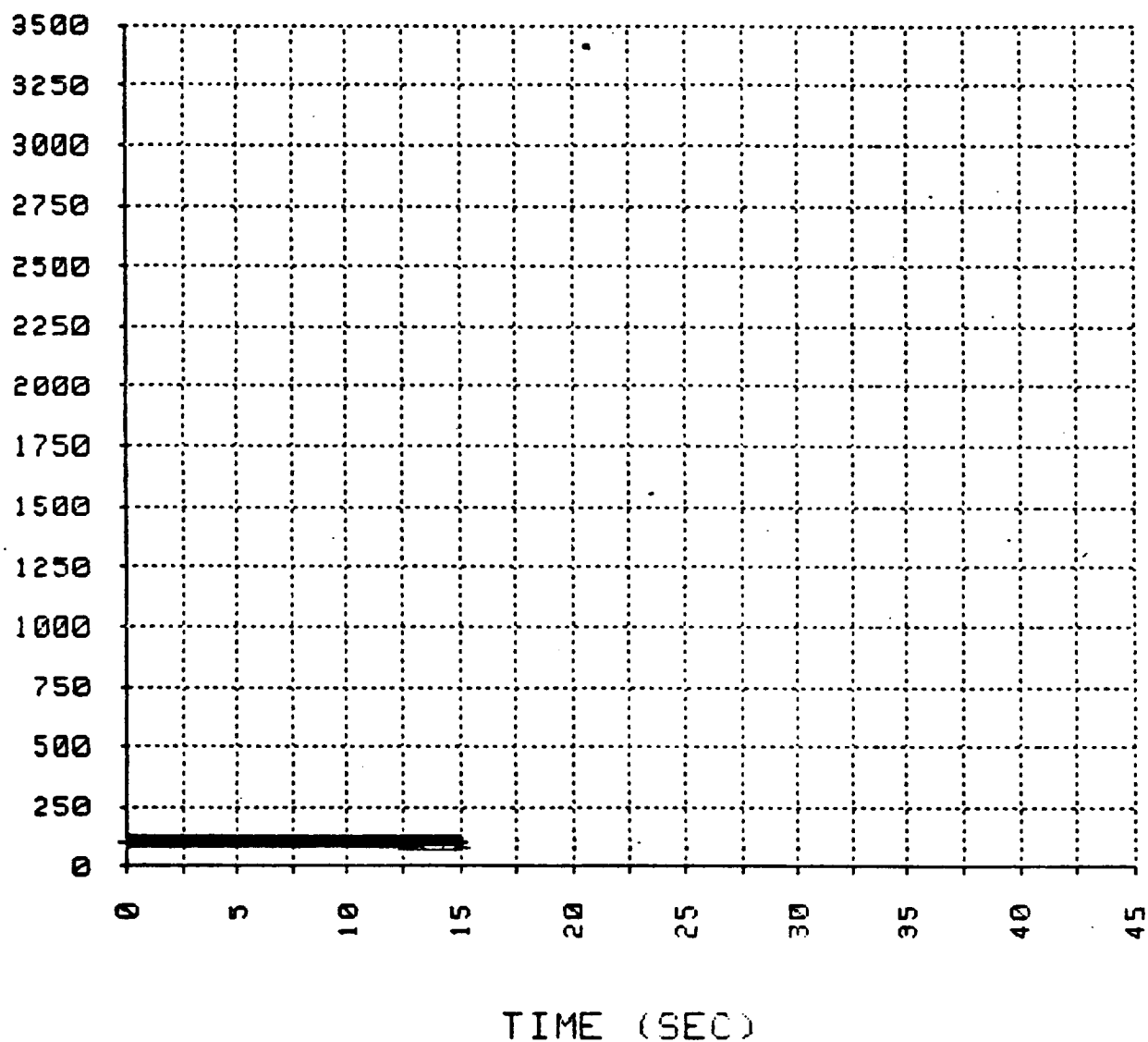


FRT #223 (100 PSIG GN2)



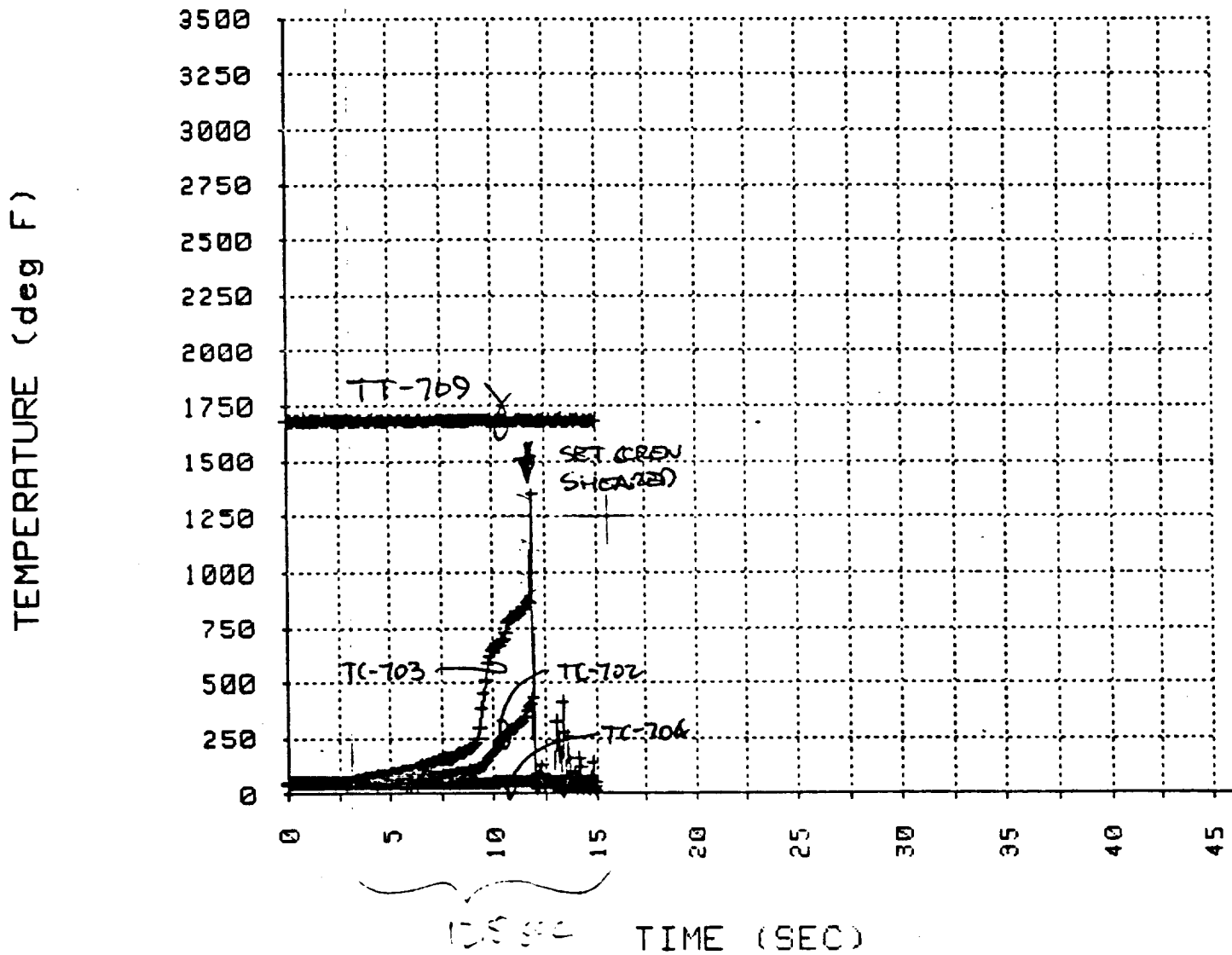
CHAMBER PRESSURE (PSIG)

FRT #223 (100 PSIG GN2)

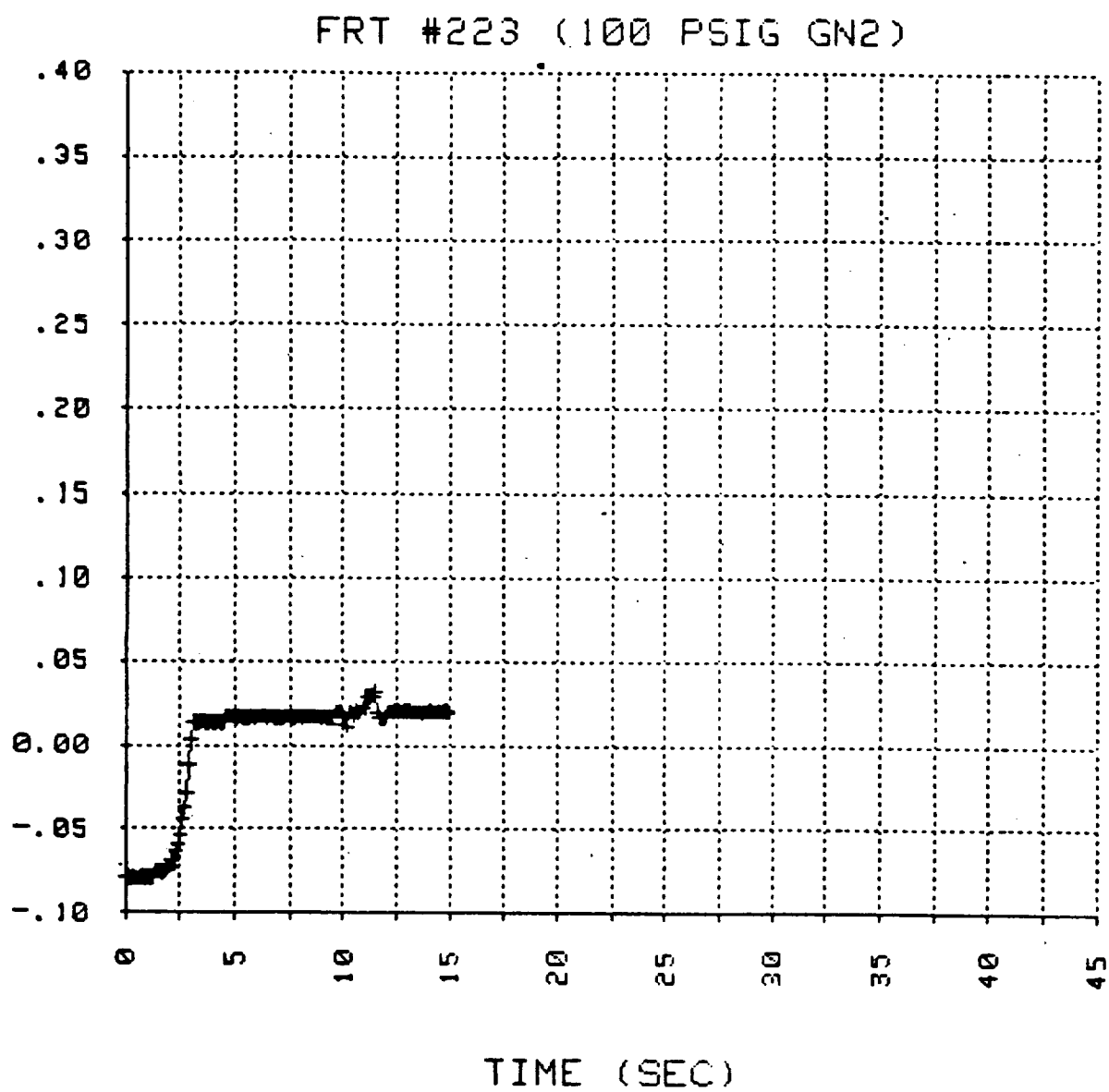


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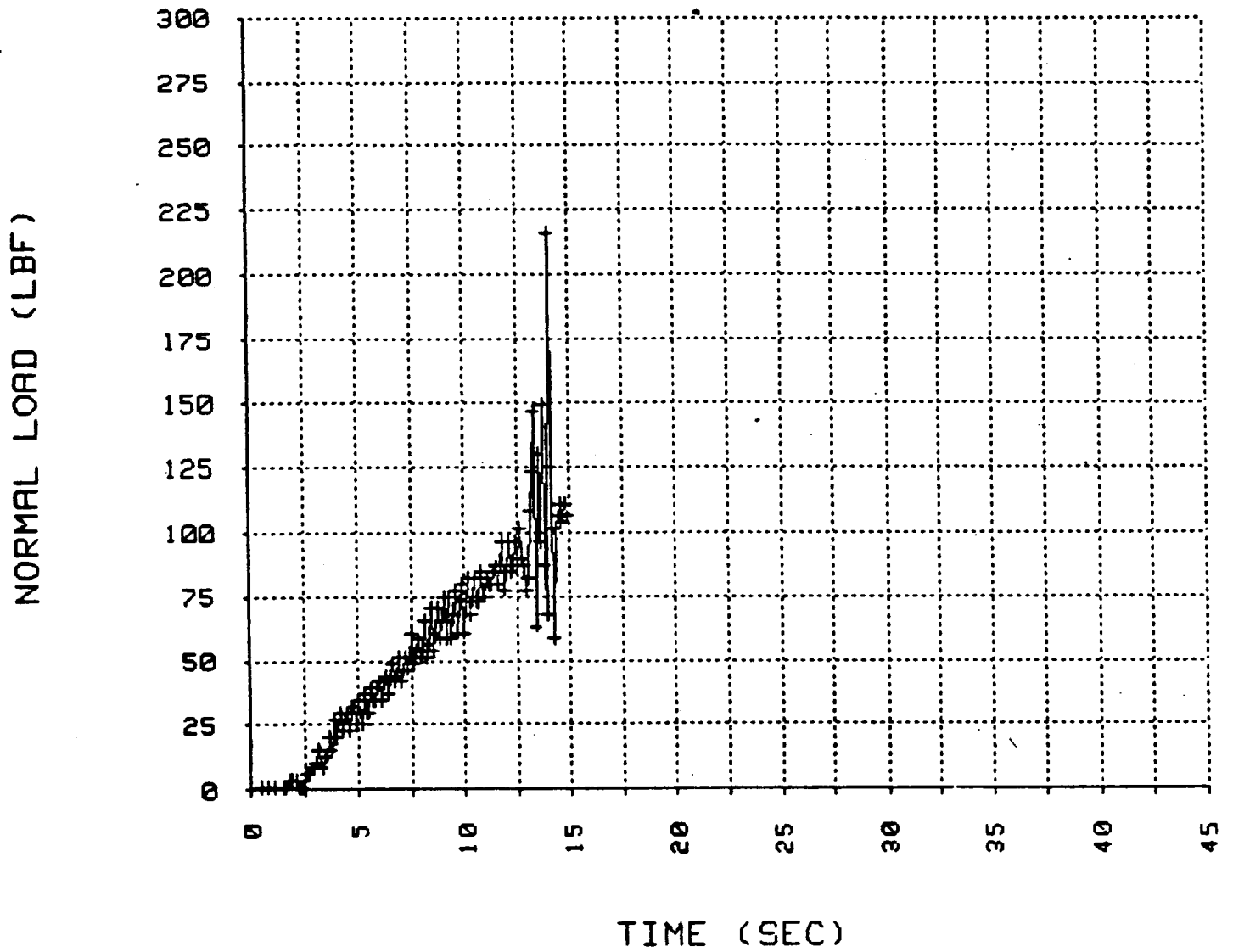
FRT #223 (100 PSIG GN2)



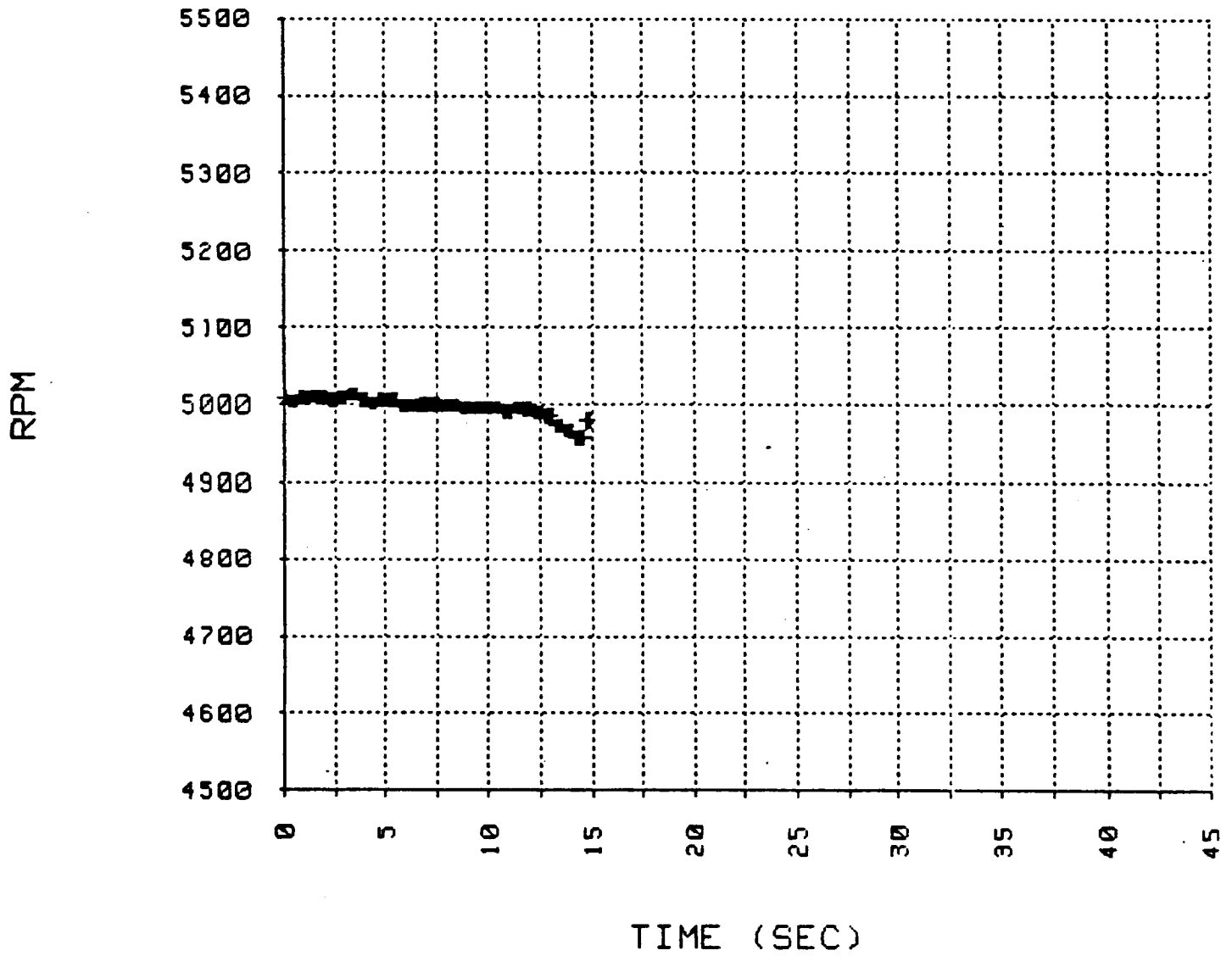
DISPLACEMENT (in)



FRT #224 (100 PSIG GN2)

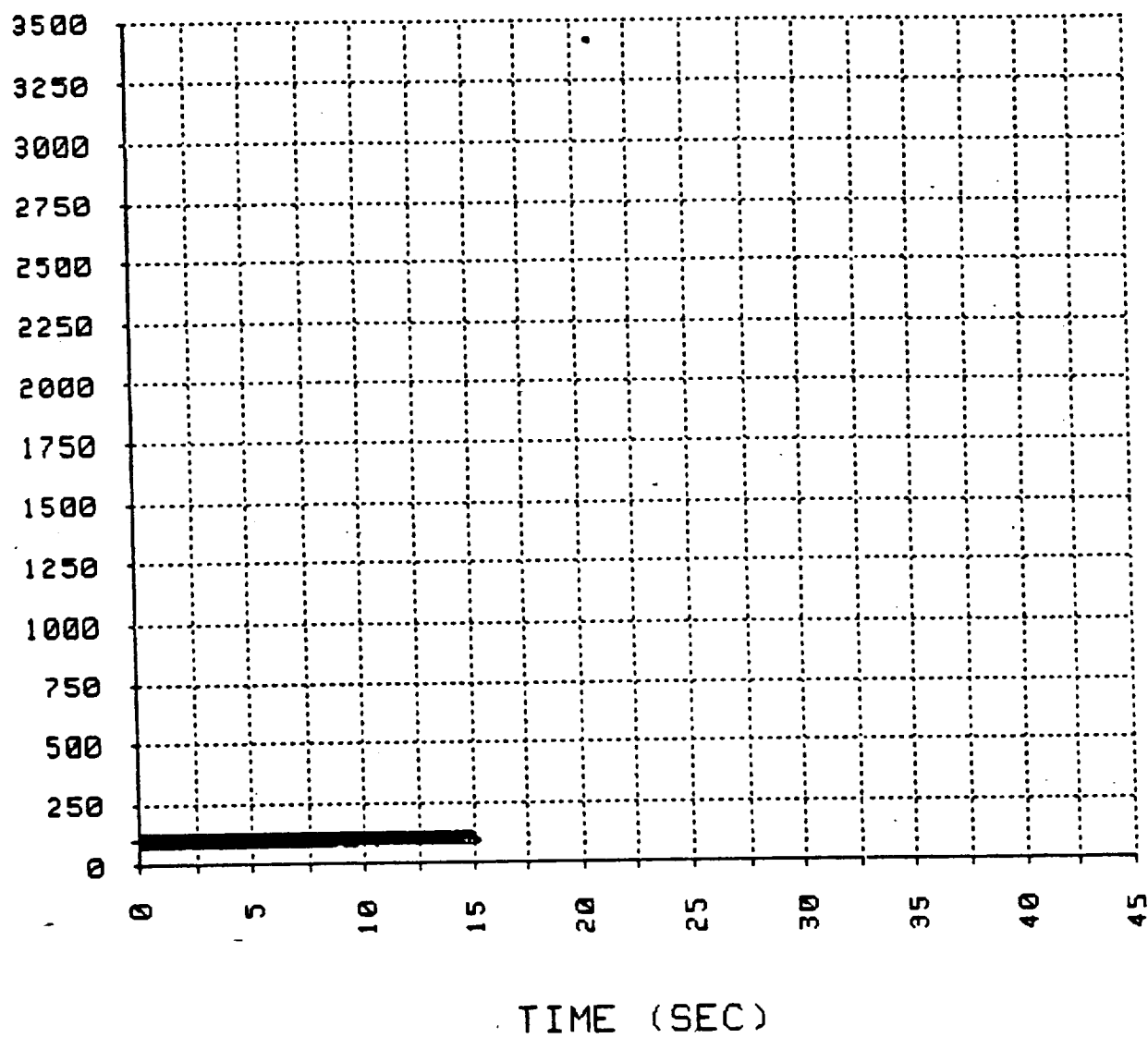


FRT #224 (100 PSIG GN2)

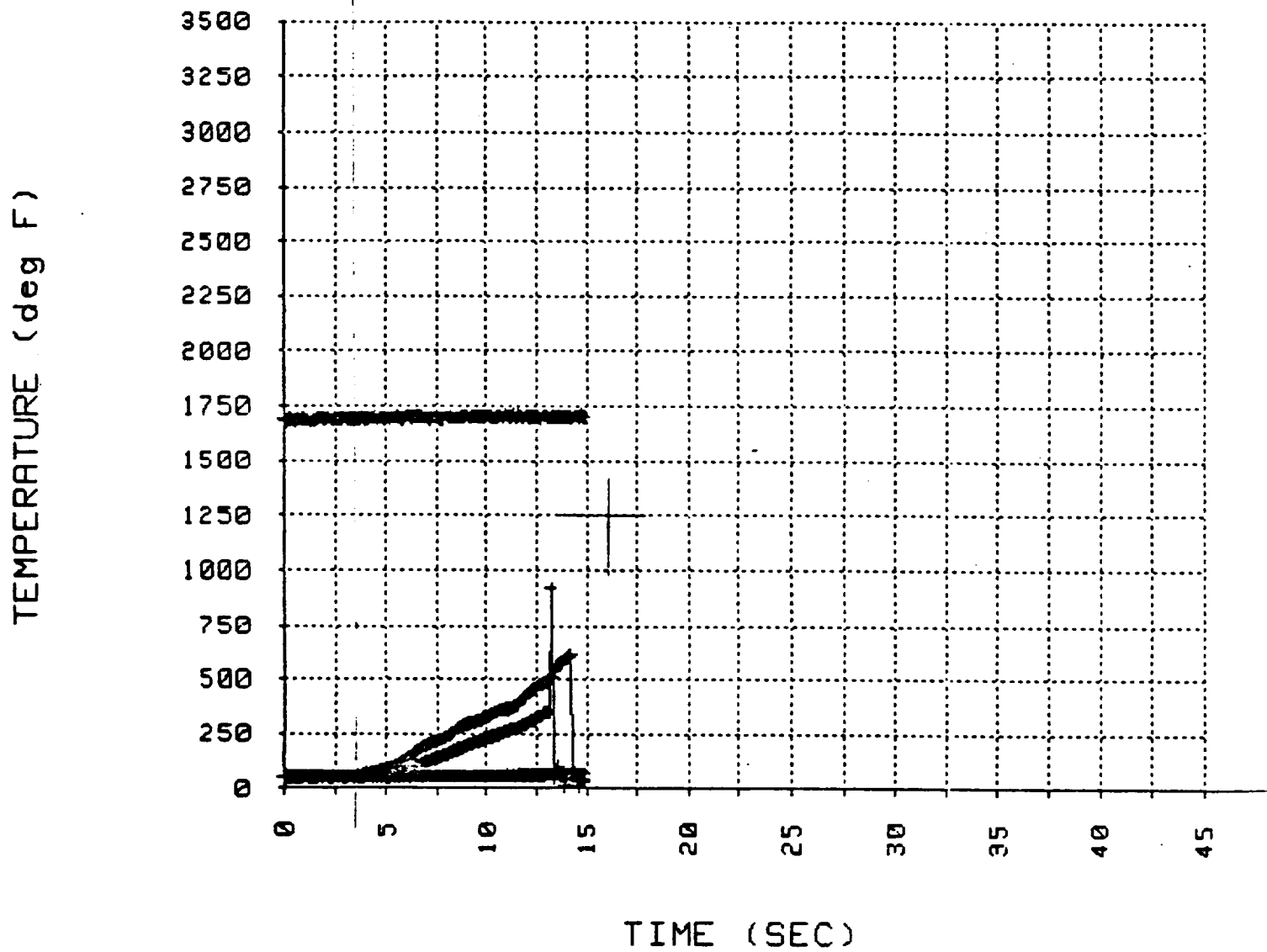


CHAMBER PRESSURE (PSIG)

FRT #224 (100 PSIG GN2)

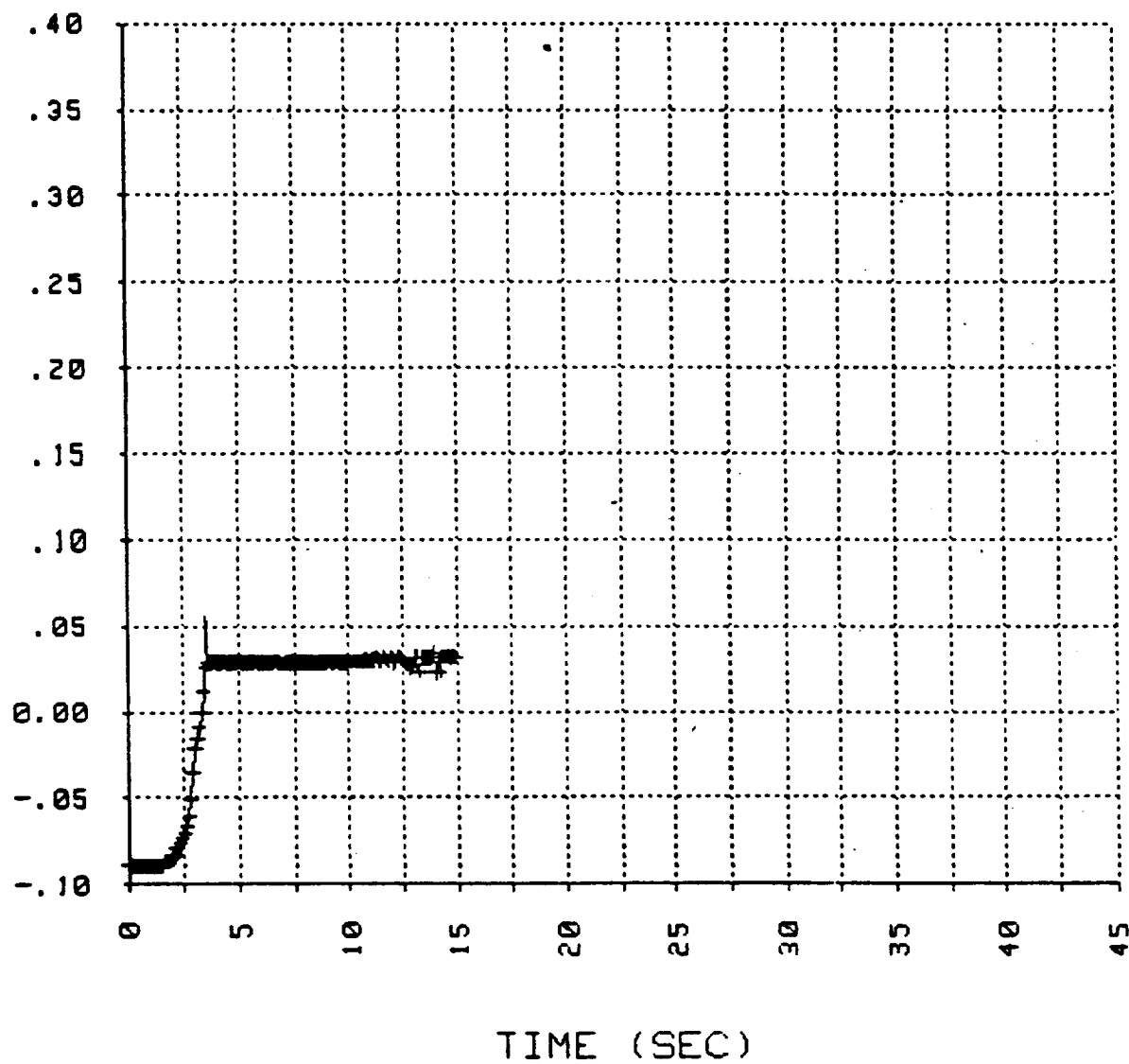


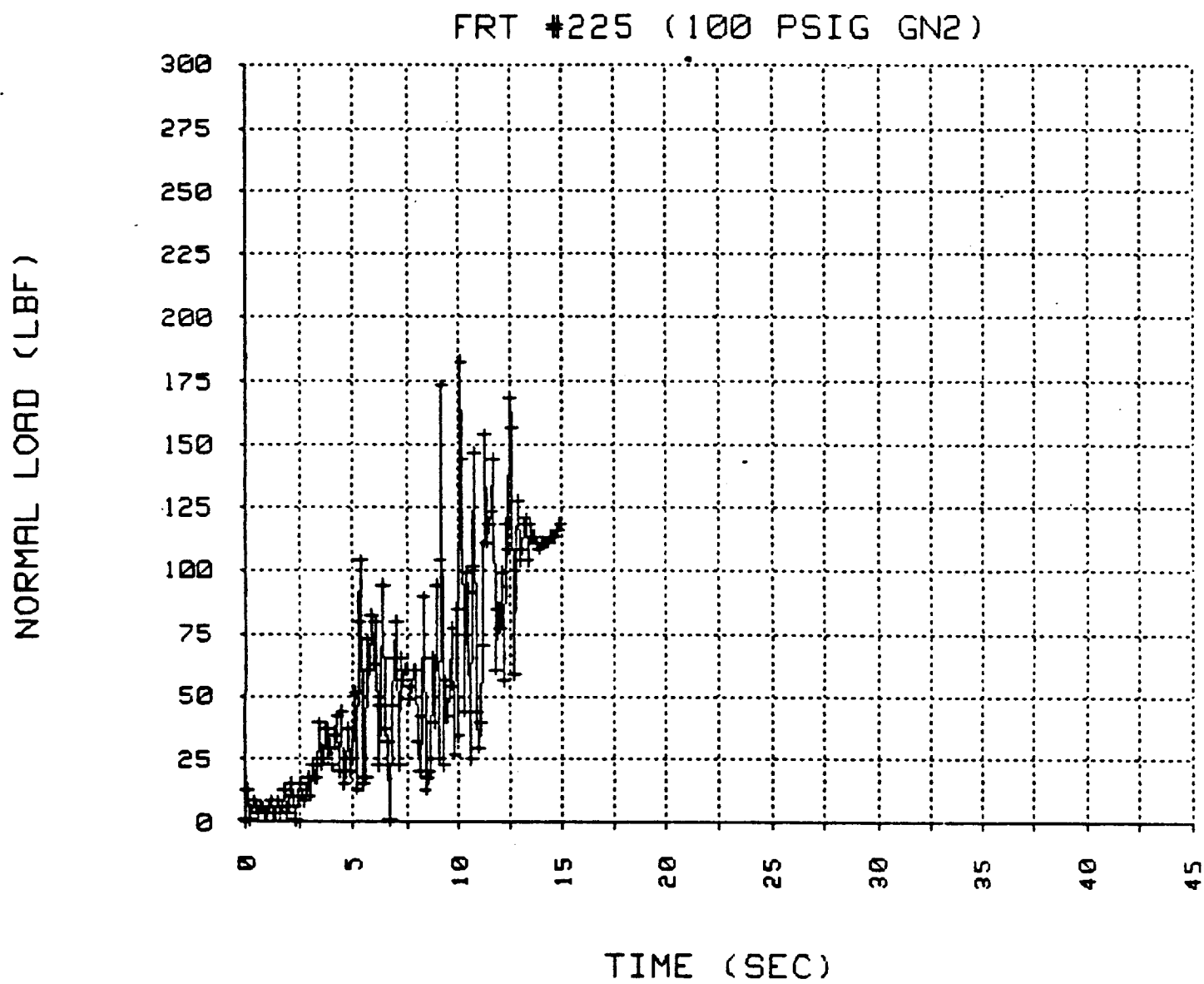
FRT #224 (100 PSIG GN2)



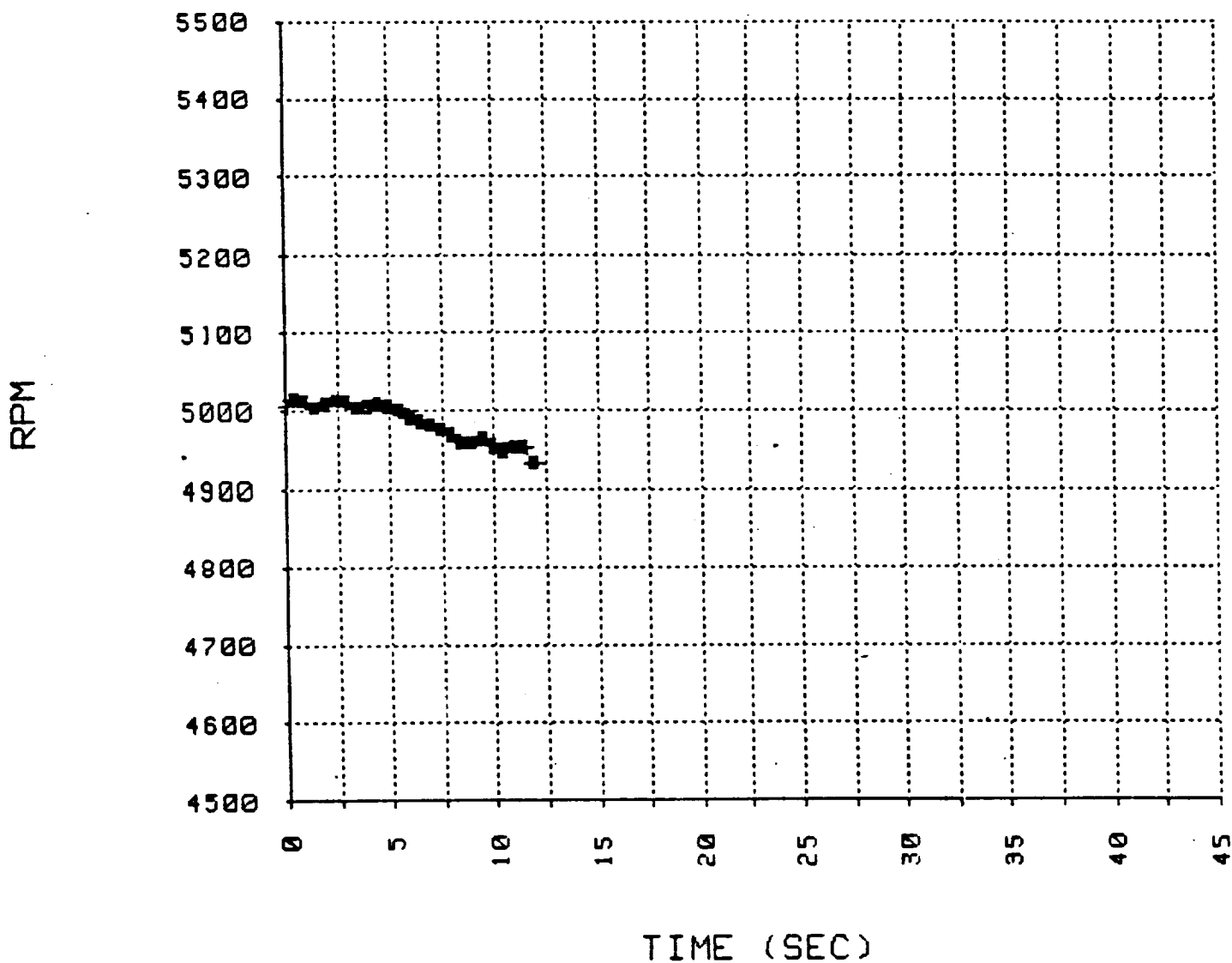
DISPLACEMENT (in)

FRT #224 (100 PSIG GN2)



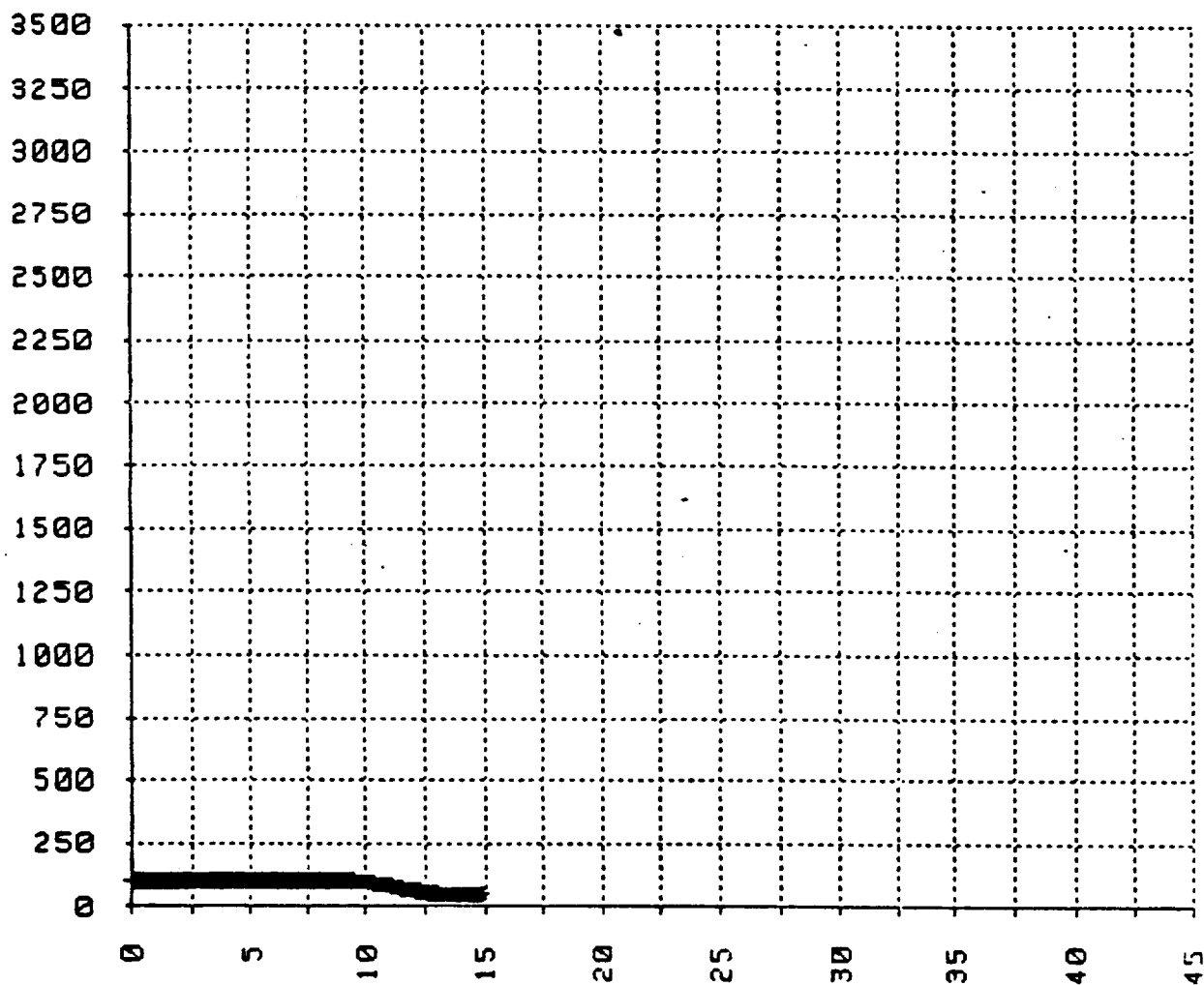


FRT #225 (100 PSIG GN2)



CHAMBER PRESSURE (PSIG)

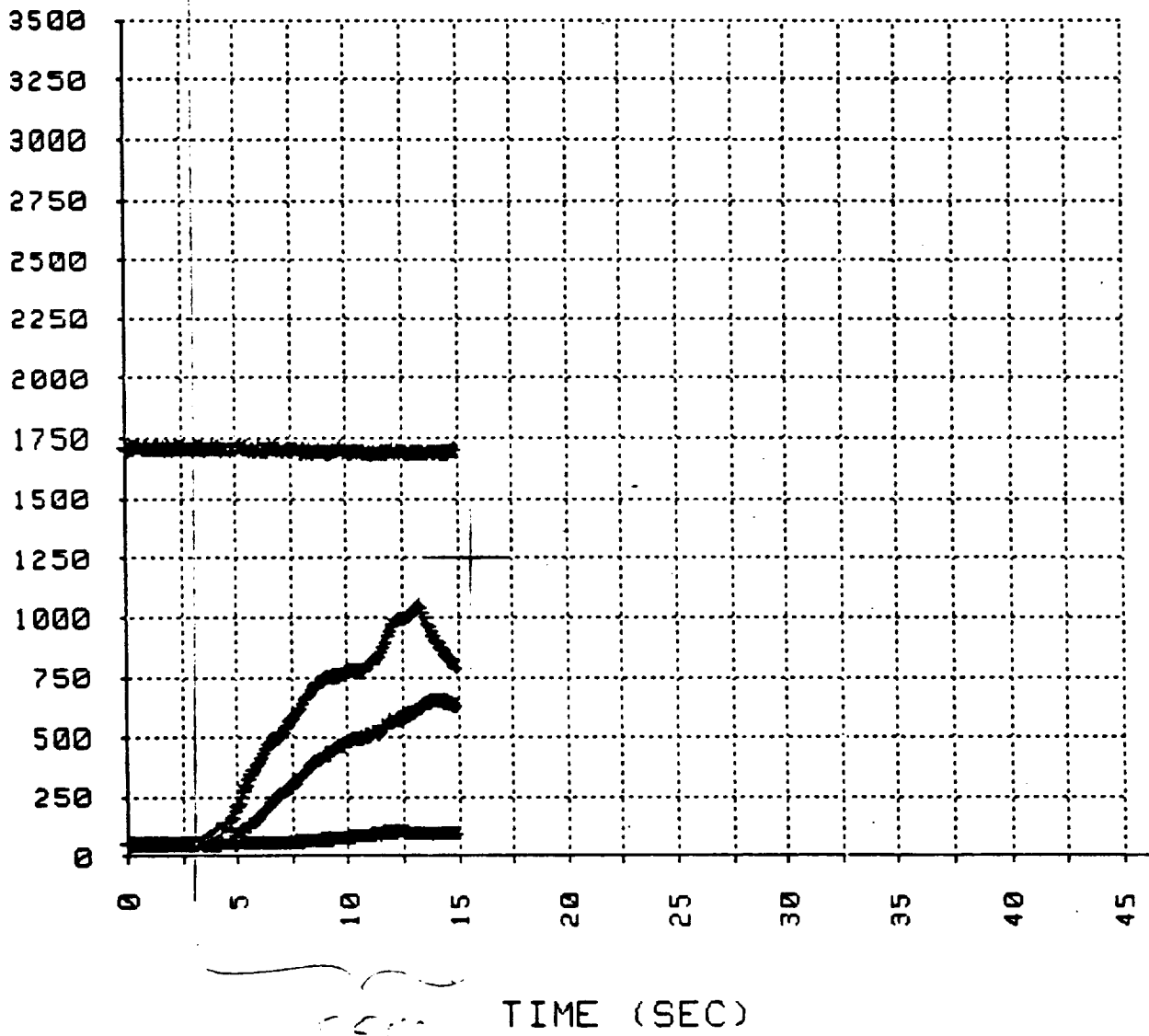
FRT #225 (100 PSIG GN2)



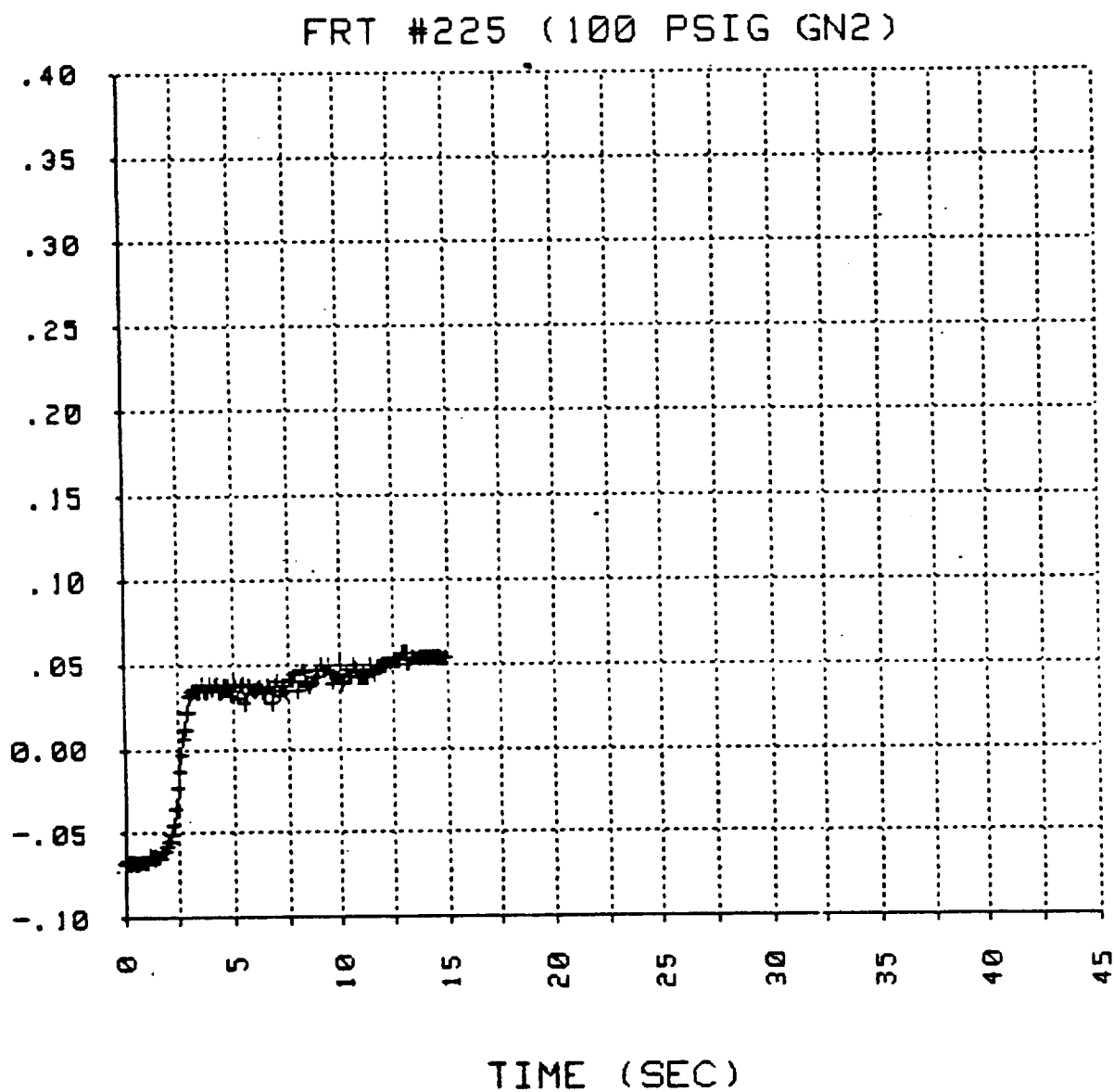
TIME (SEC)

TEMPERATURE (deg F)

FRT #225 (100 PSIG GN2)

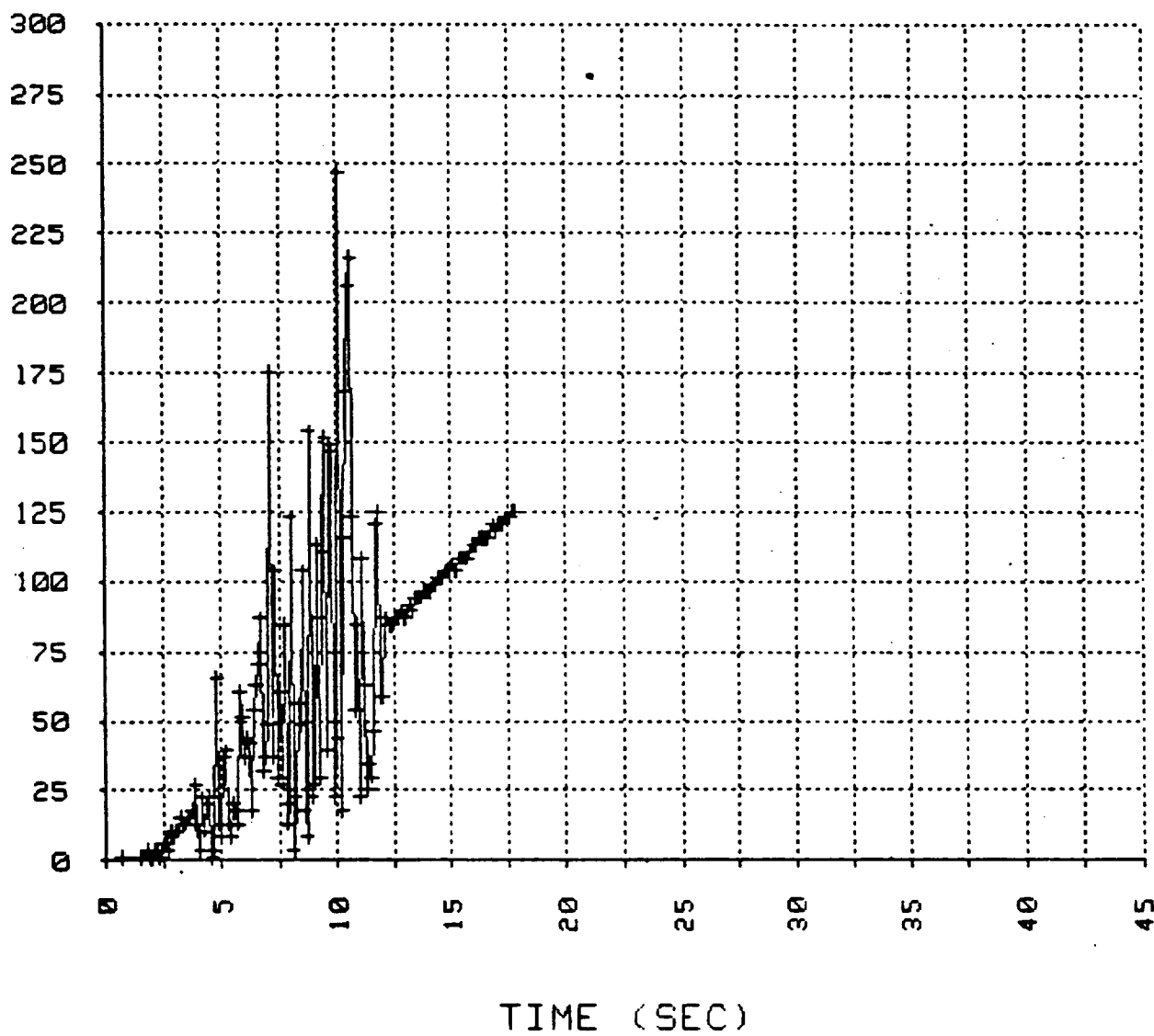


DISPLACEMENT (in)

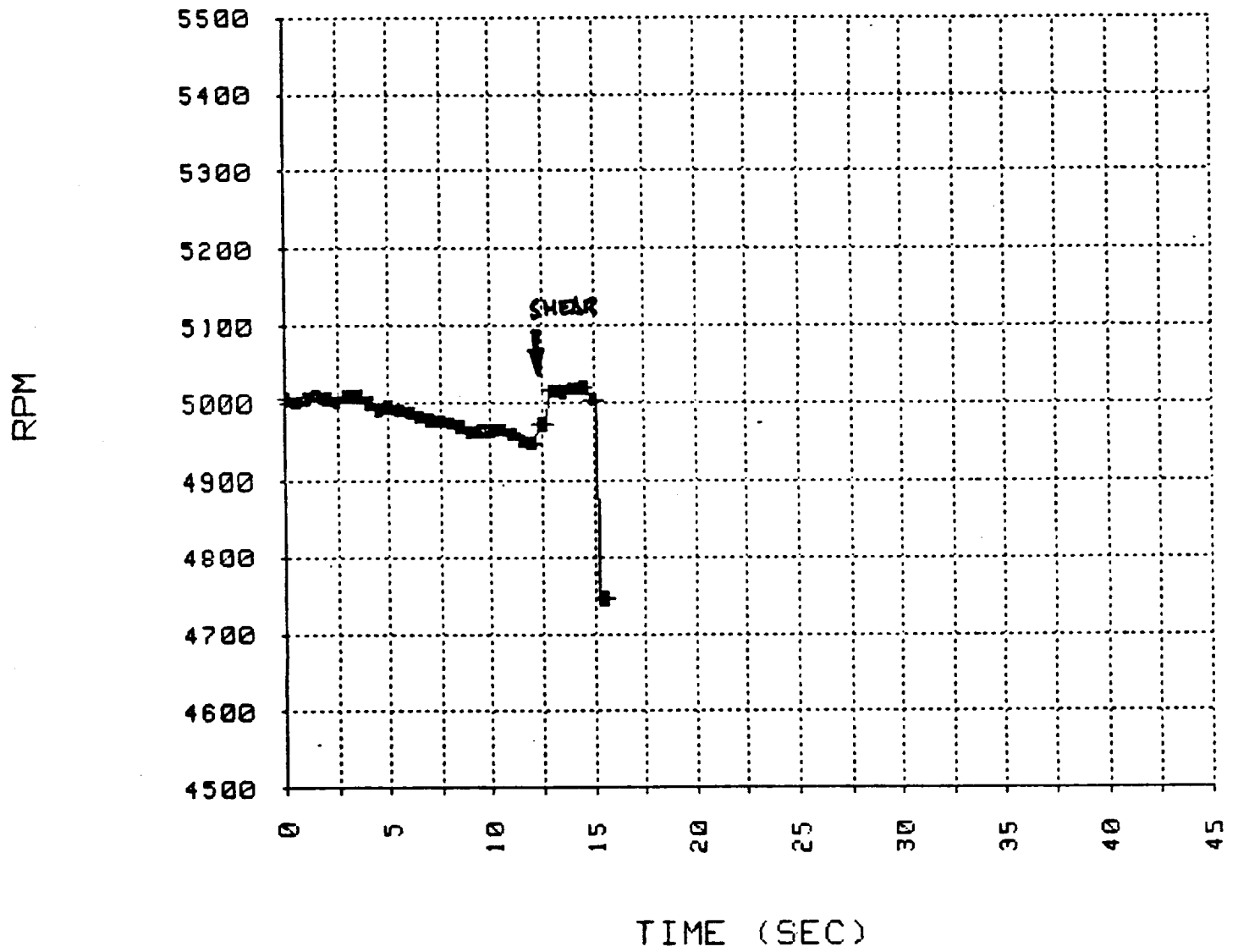


NORMAL LOAD (LBF)

FRT #226 (1000 PSIG GN2)

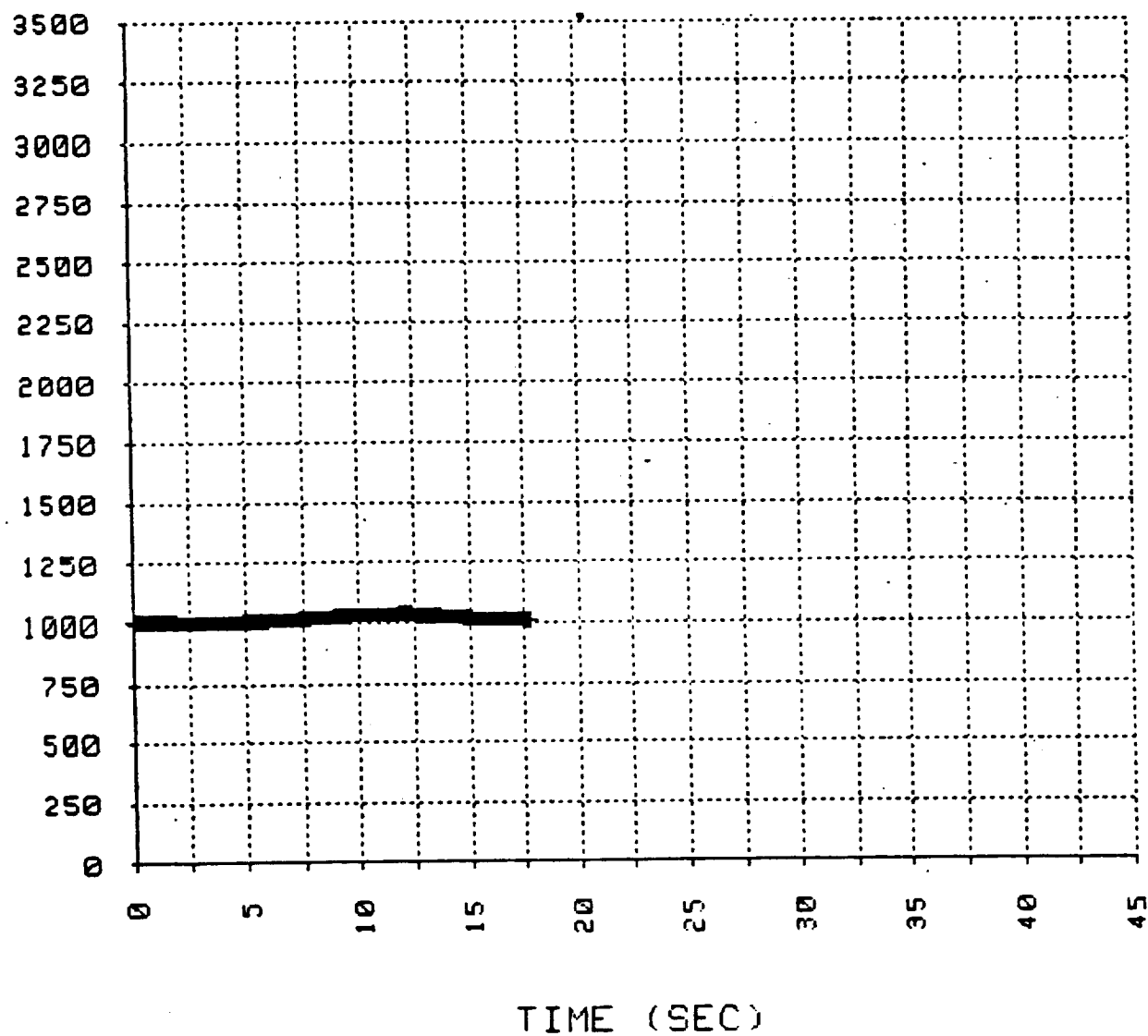


FRT #226 (1000 PSIG GN2)



CHAMBER PRESSURE (PSIG)

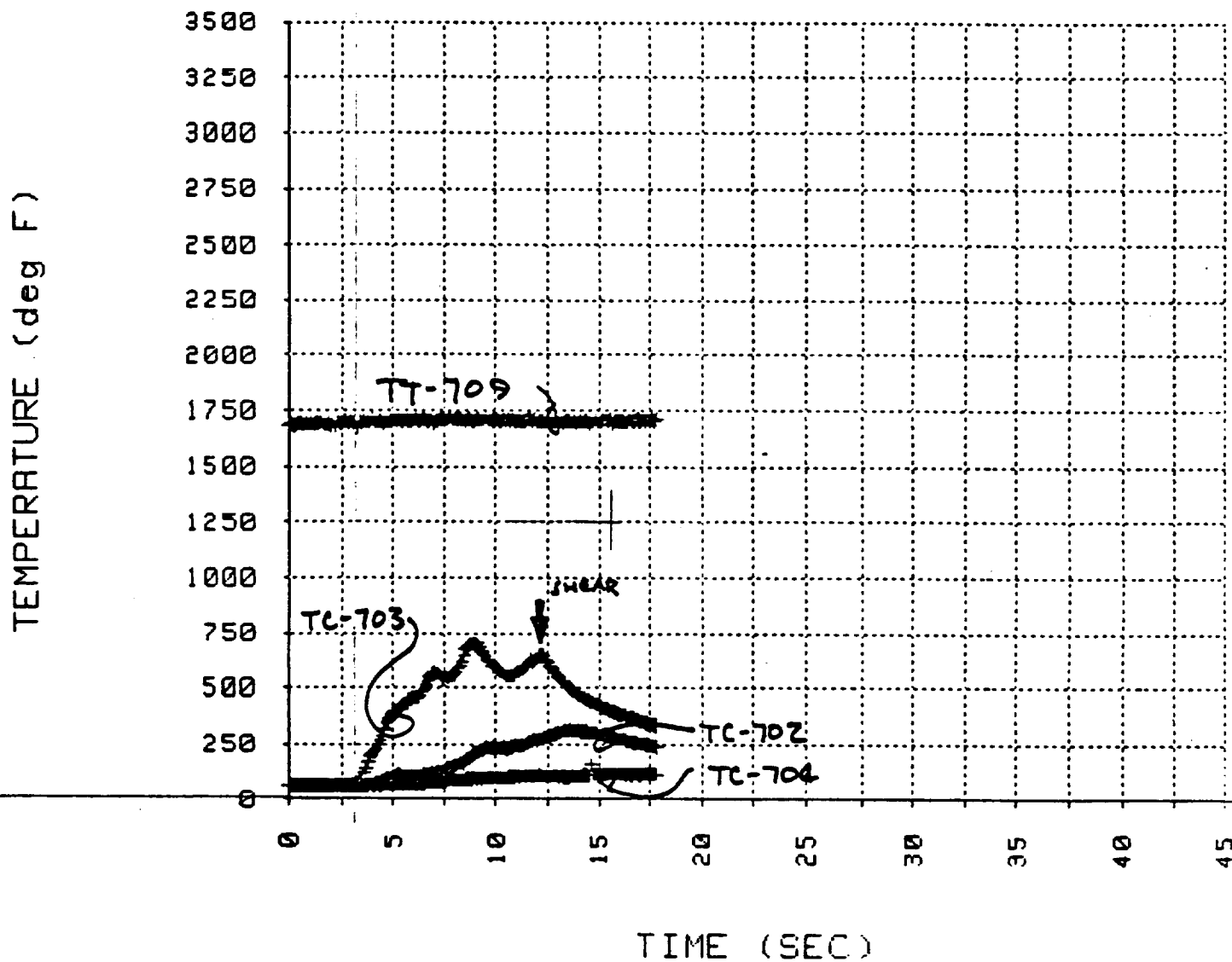
FRT #226 (1000 PSIG GN2)



F-90

C-2

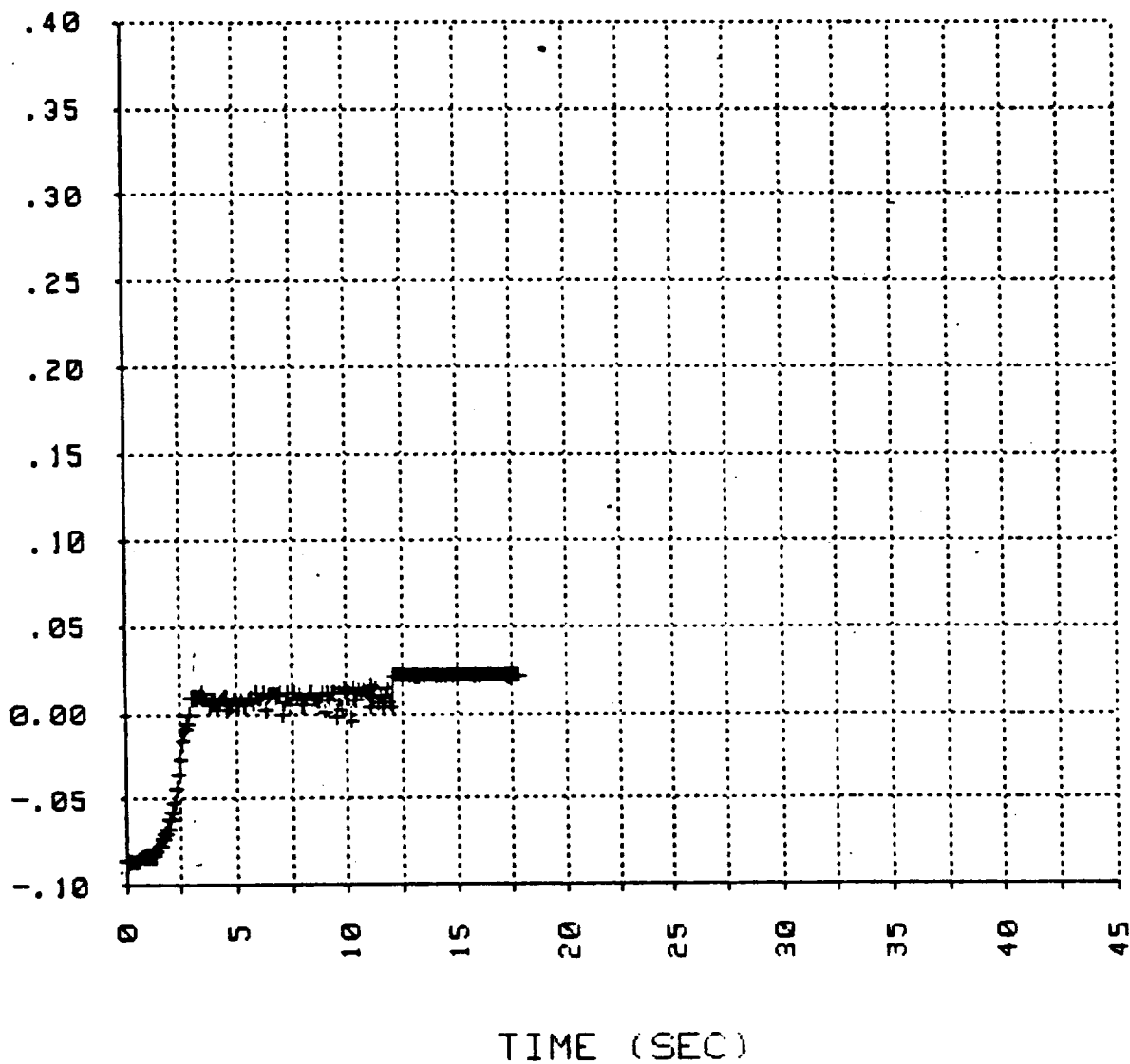
FRT #226 (1000 PSIG GN2)



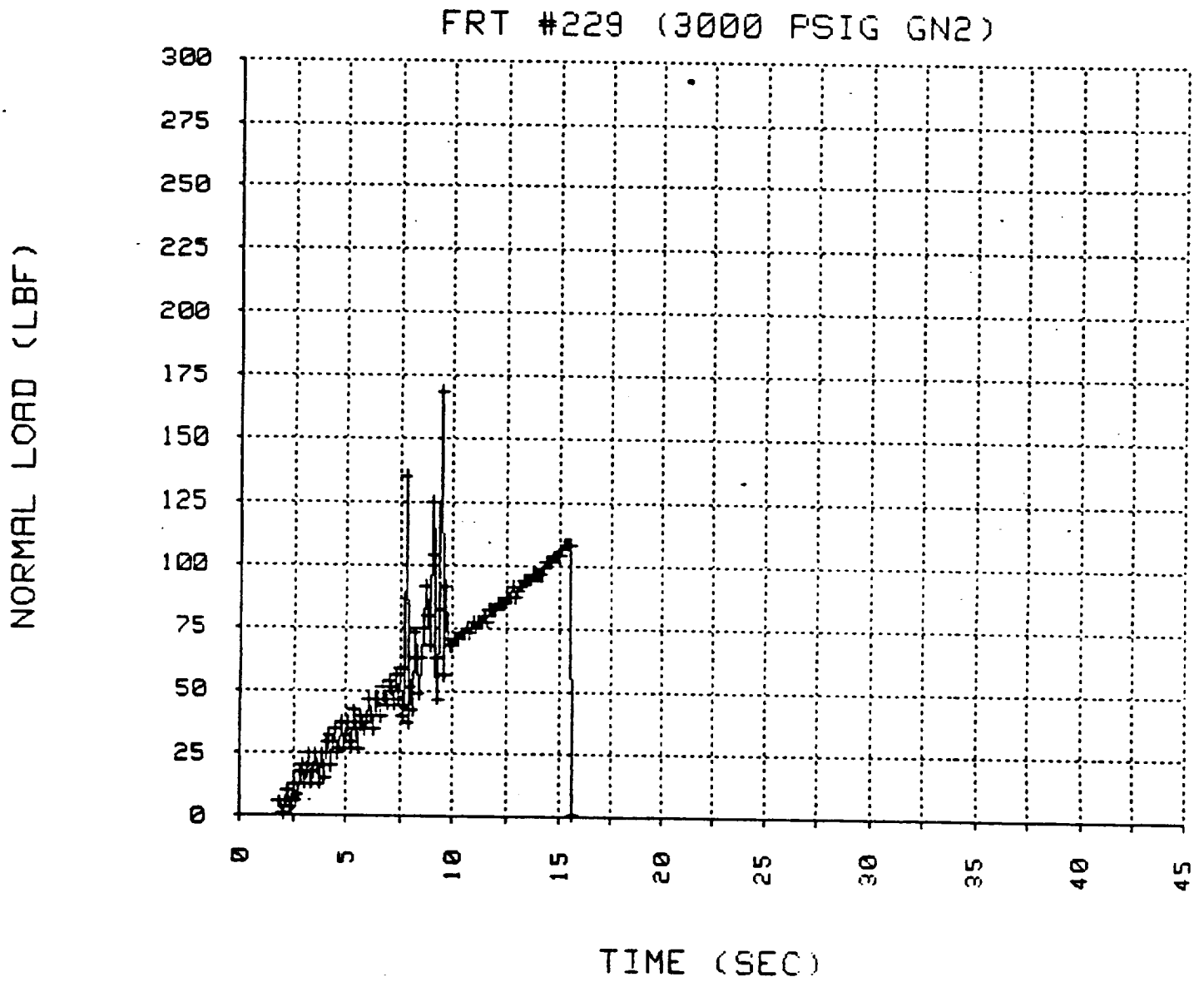
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DISPLACEMENT (in)

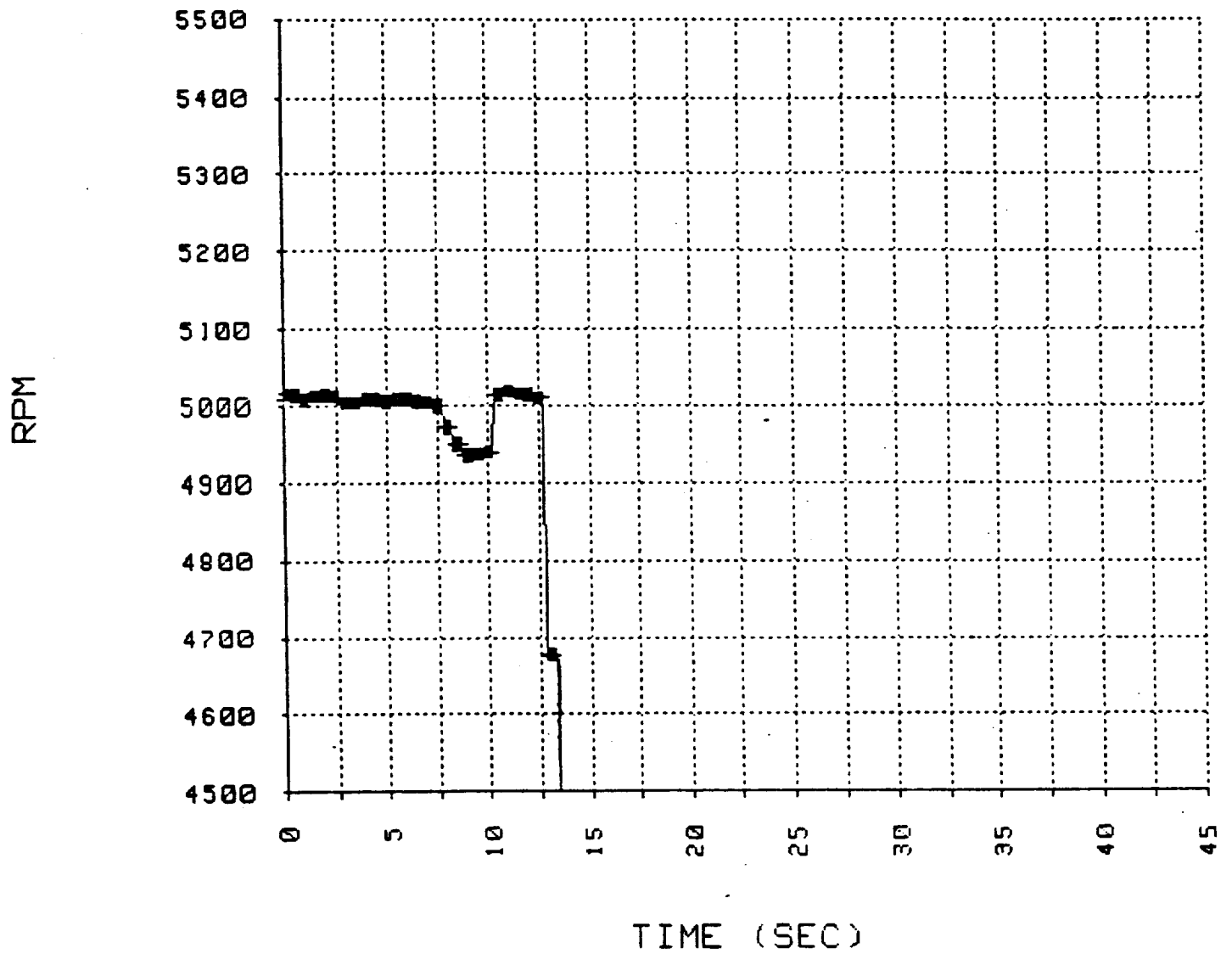
FRT #226 (1000 PSIG GN2)



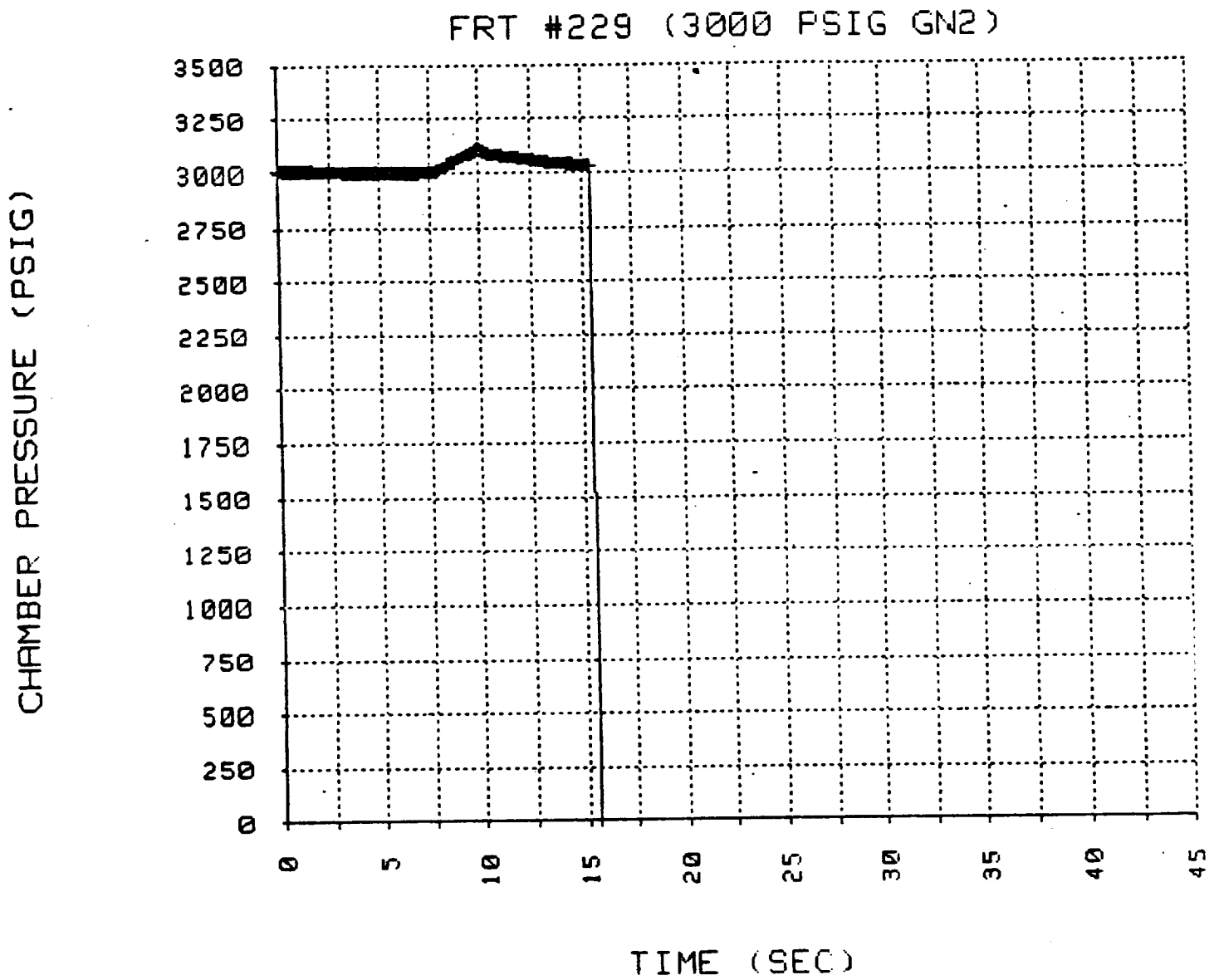
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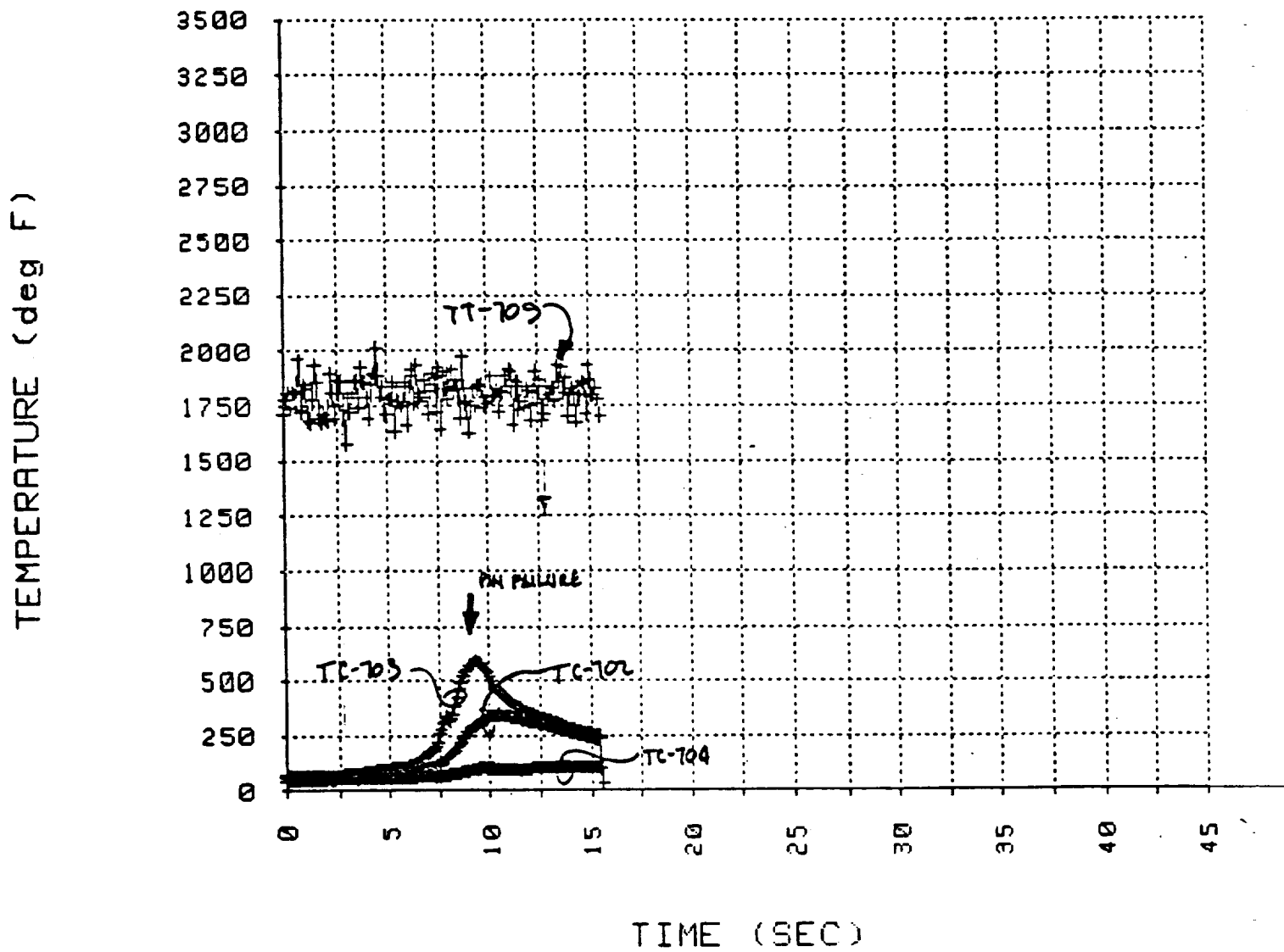
FRT #229 (3000 PSIG GN2)



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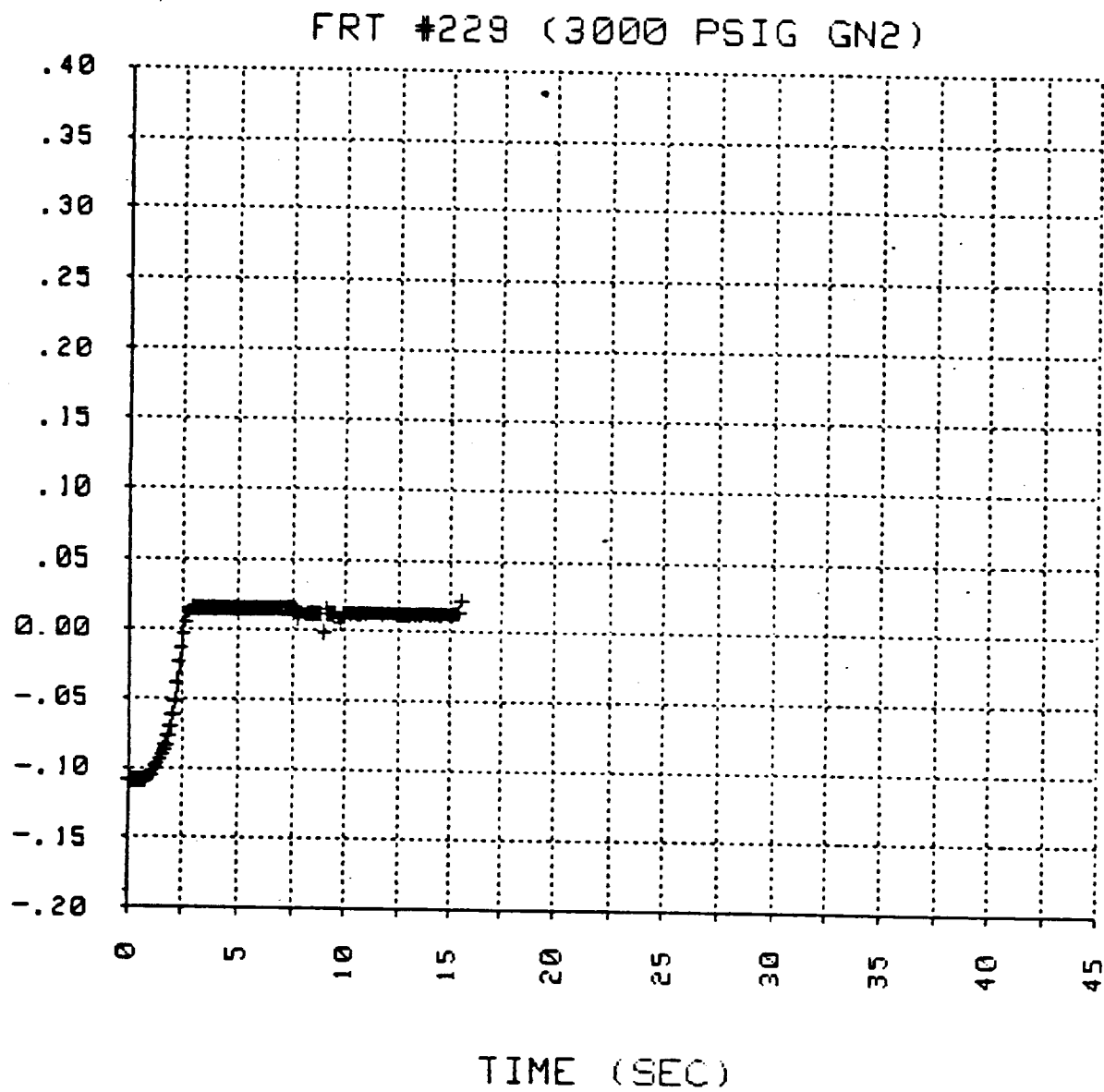


FRT #229 (3000 PSIG GN2)



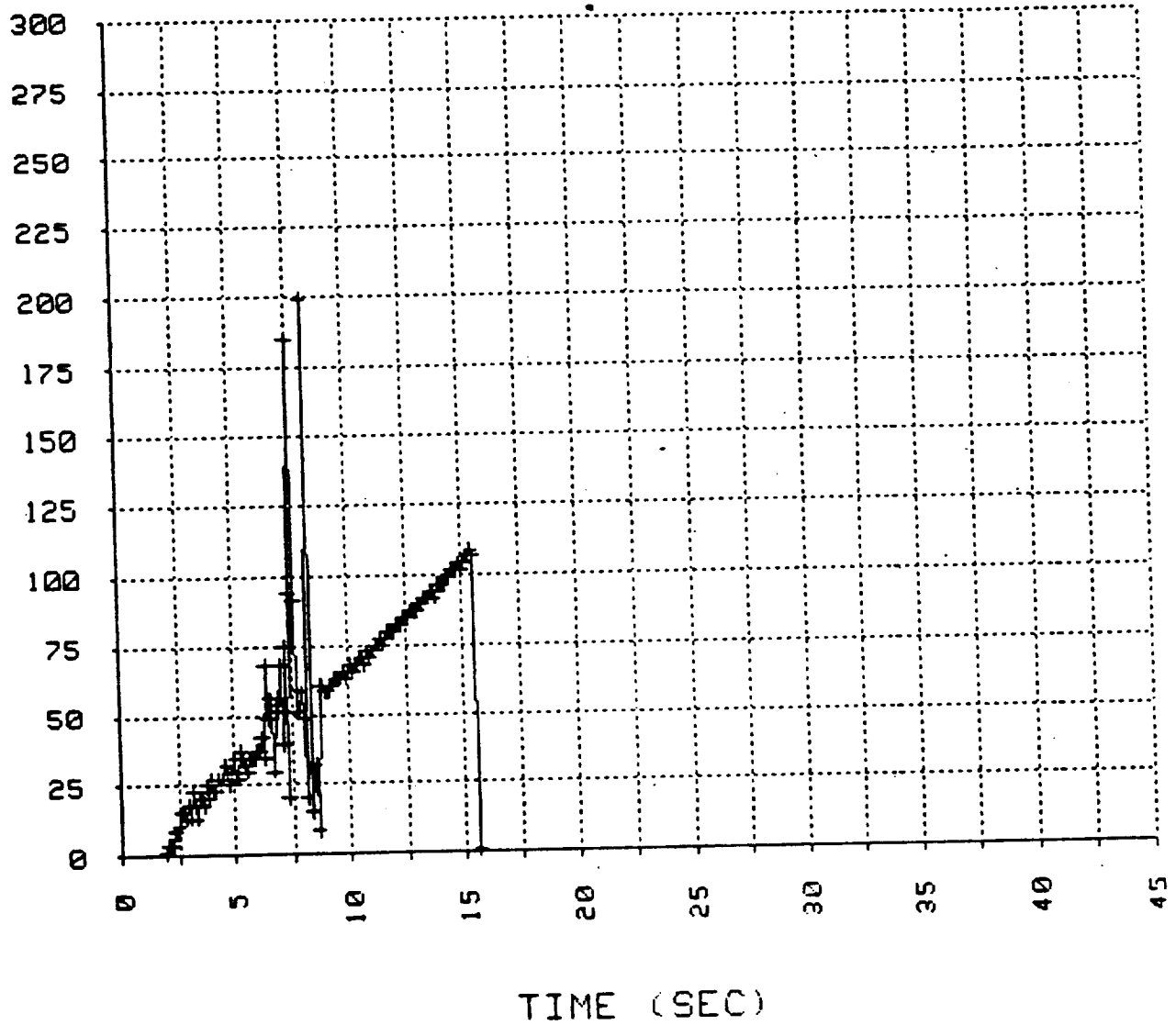
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DISPLACEMENT (in)

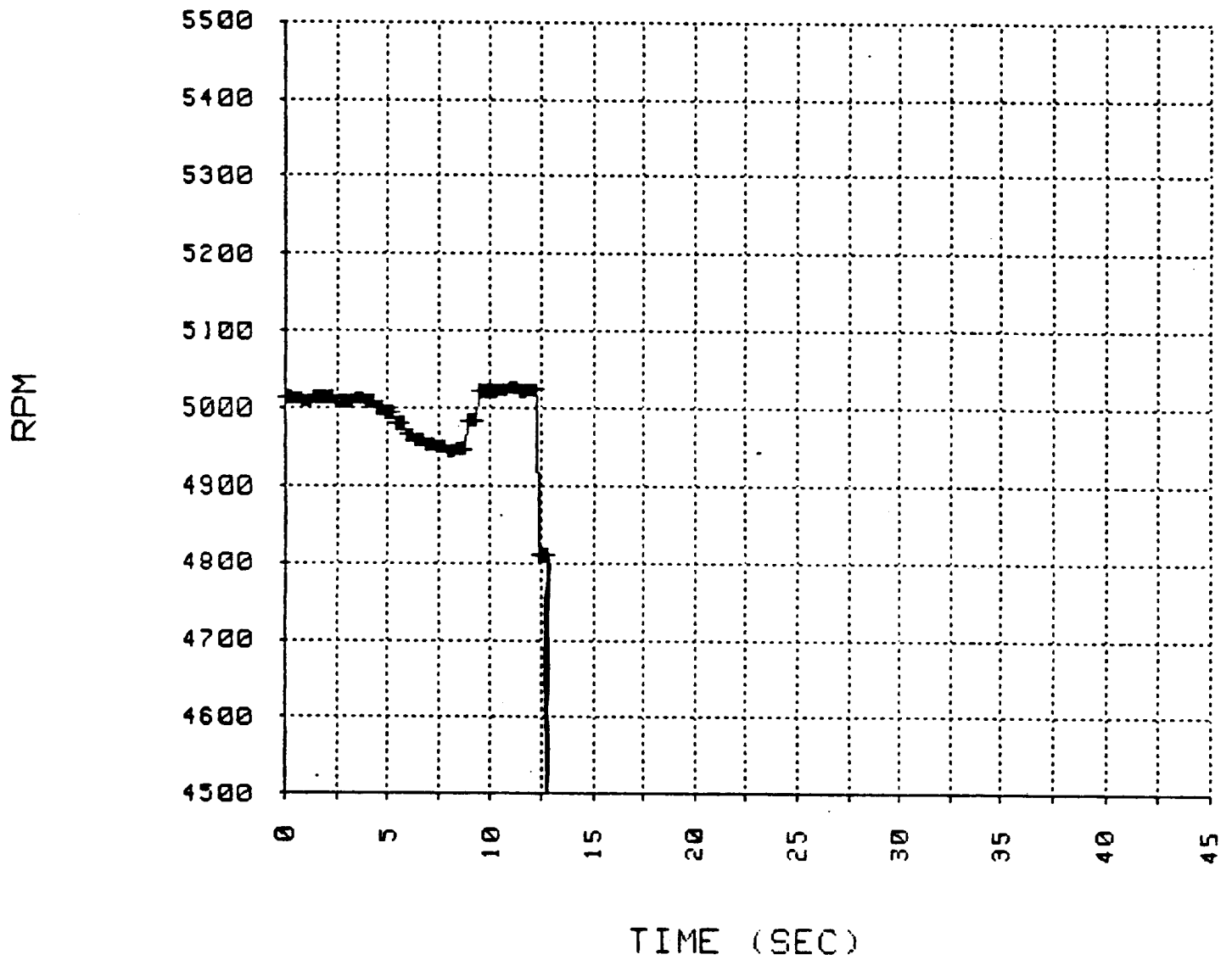


NORMAL LOAD (LBF)

FRT #230 (3000 PSIG GN2)

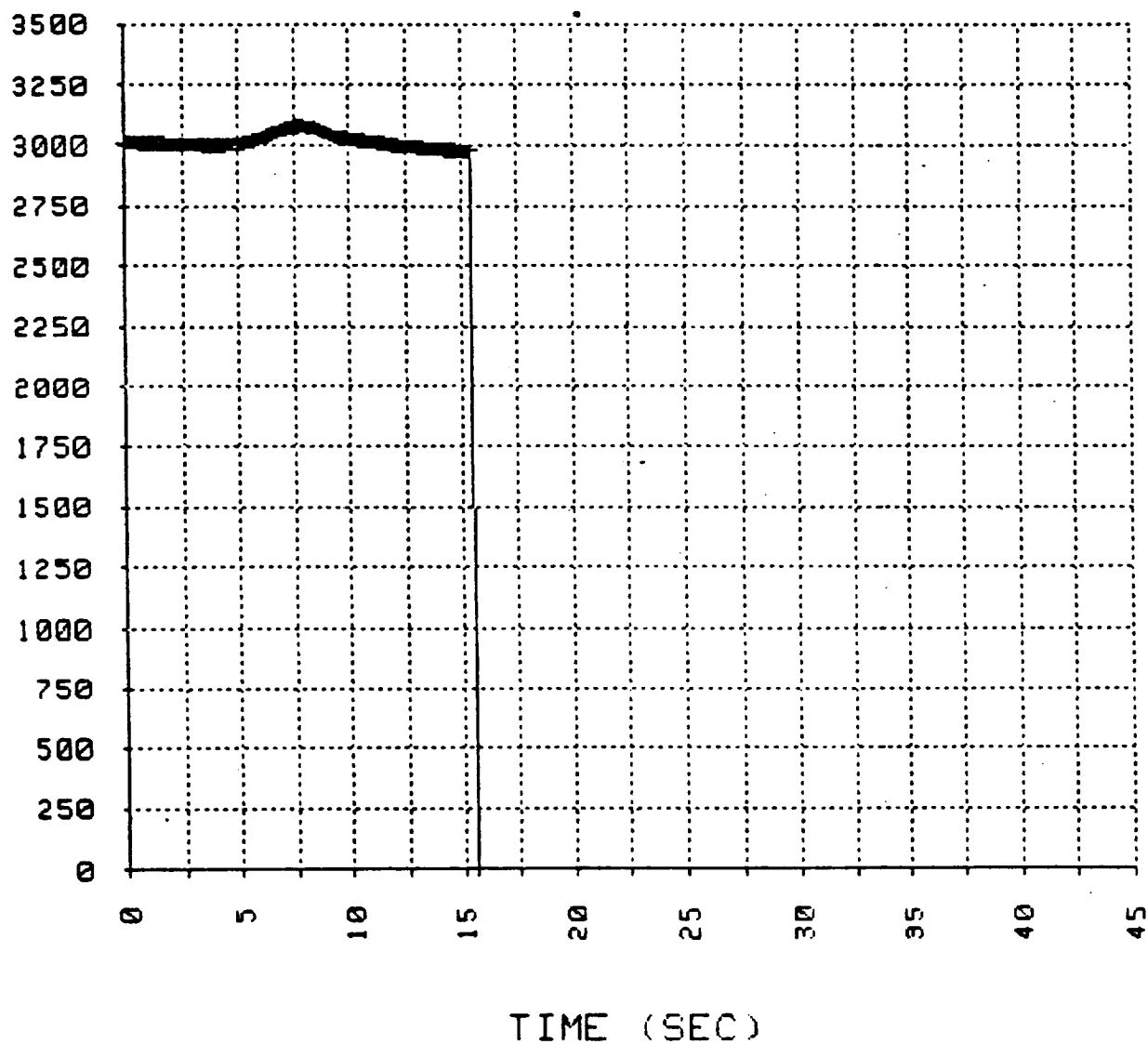


FRT #230 (3000 PSIG GN2)



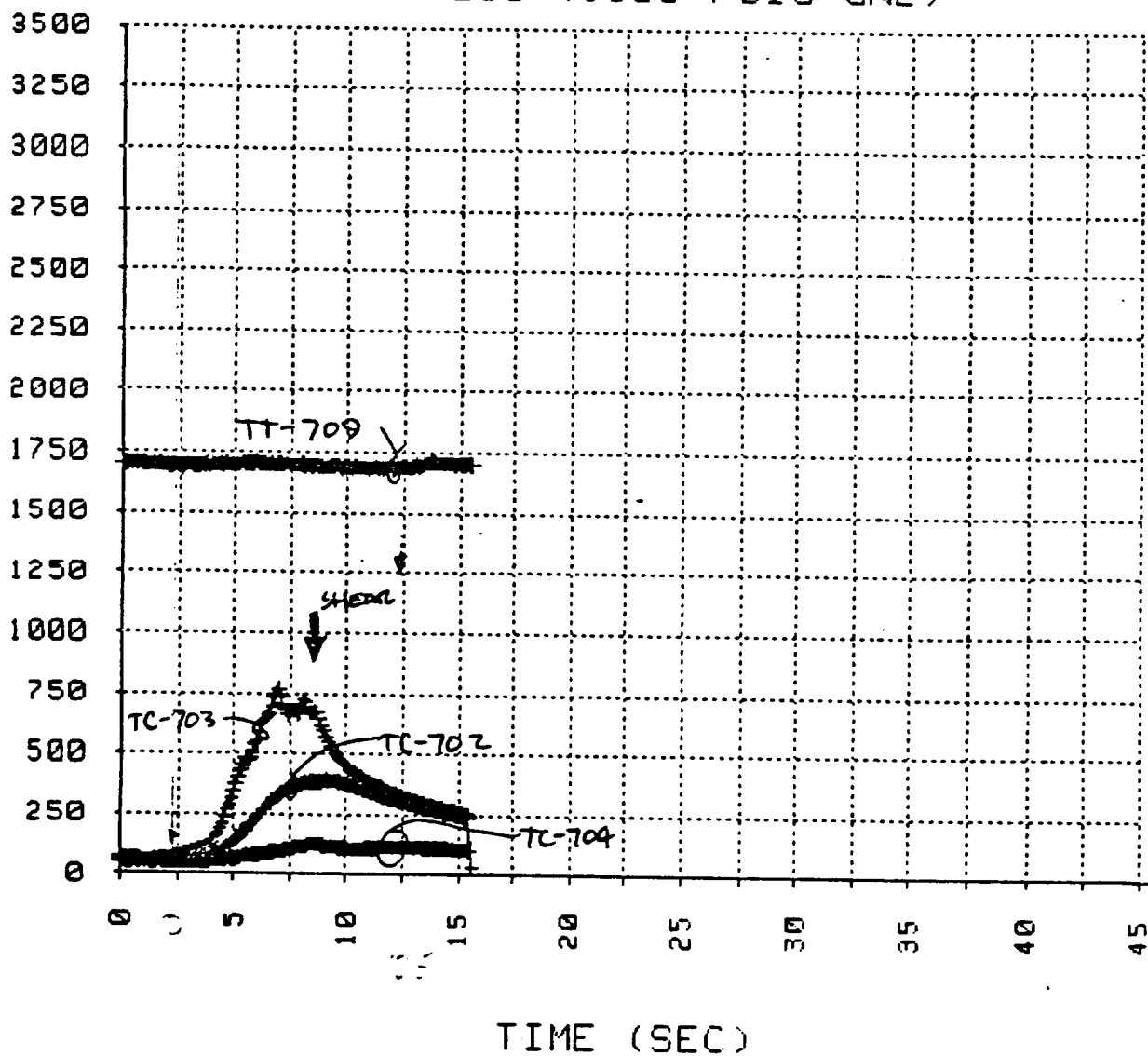
CHAMBER PRESSURE (PSIG)

FRT #230 (3000 PSIG GN2)

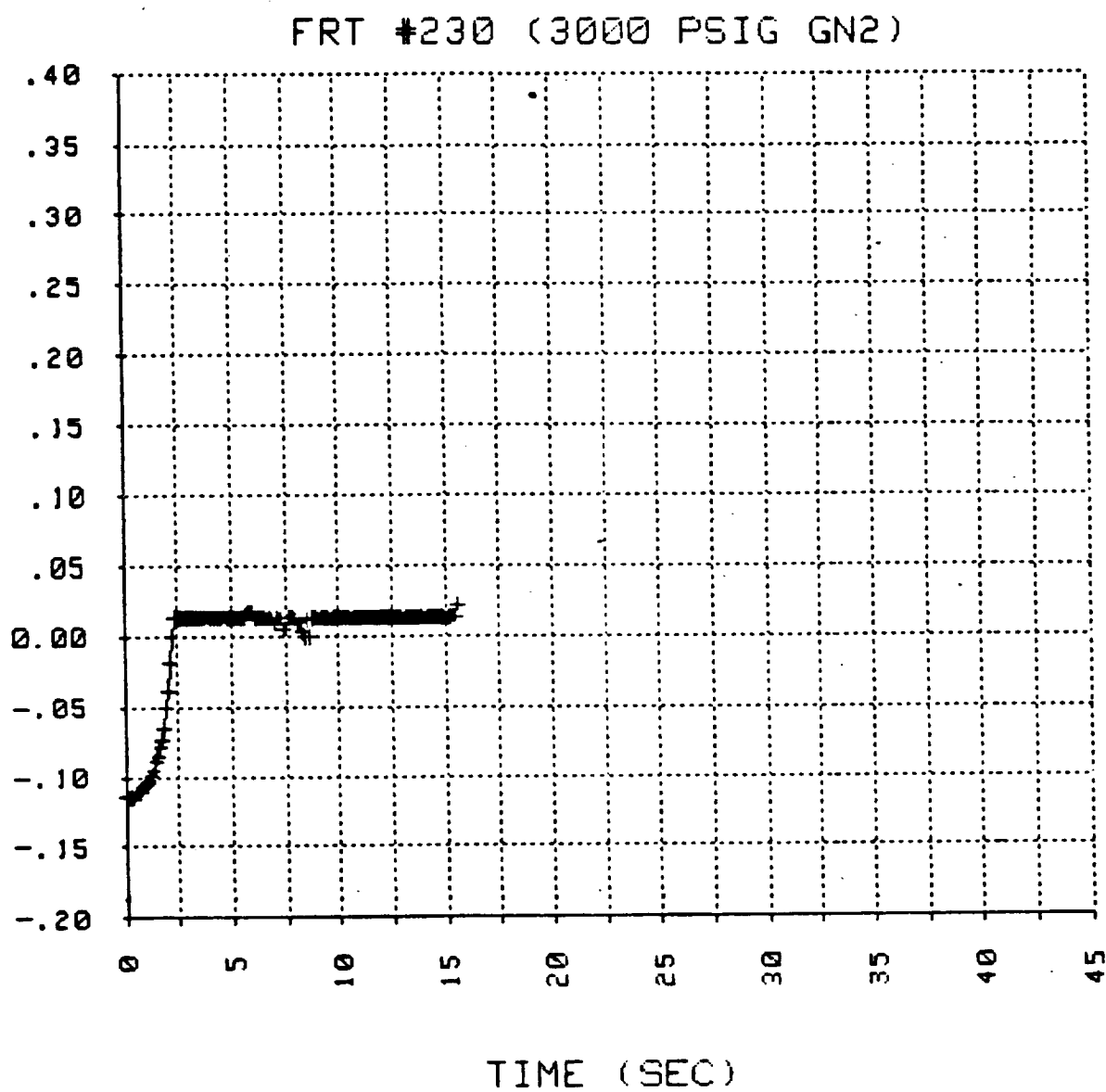


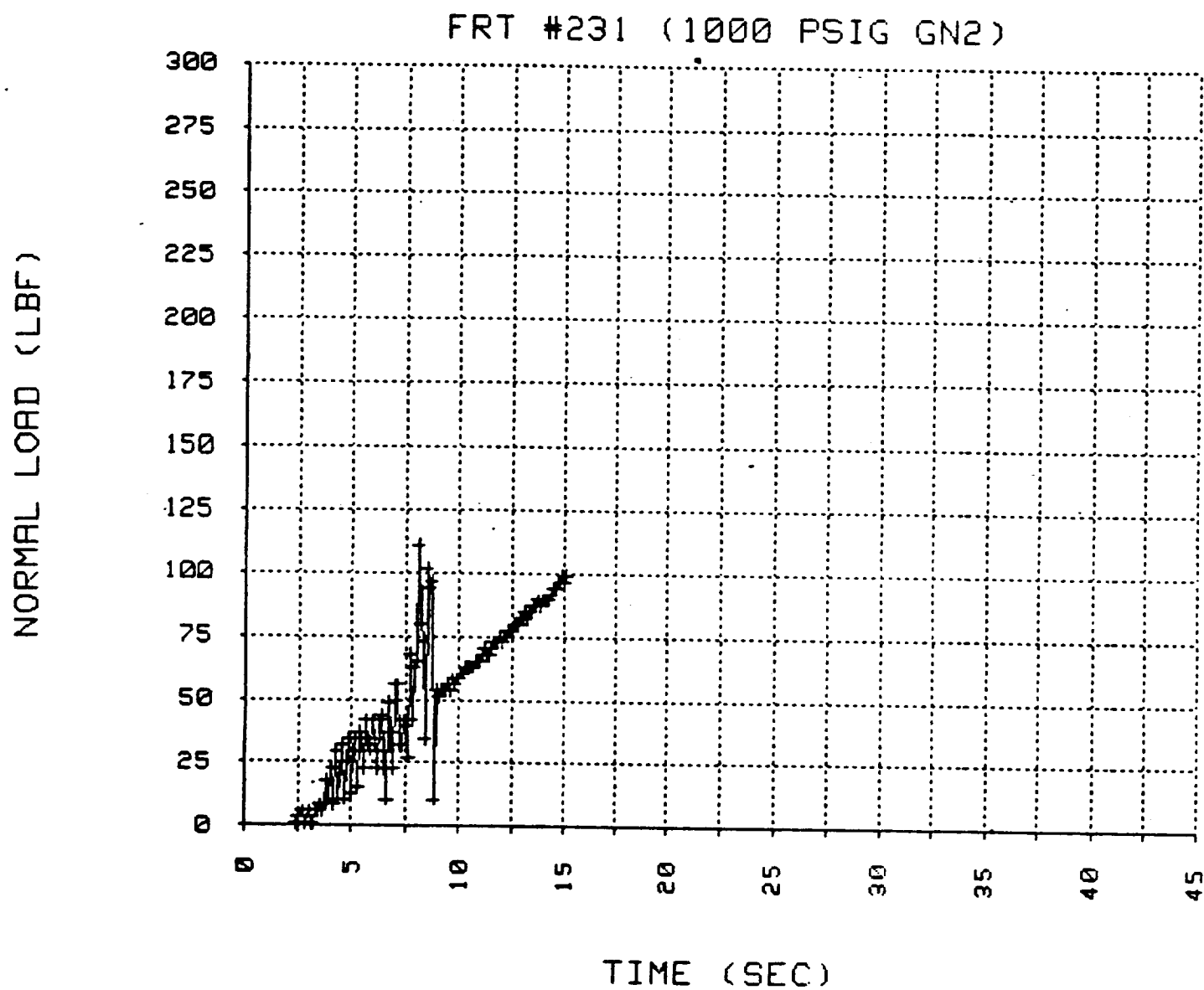
TEMPERATURE (deg F)

FRT #230 (3000 PSIG GN2)

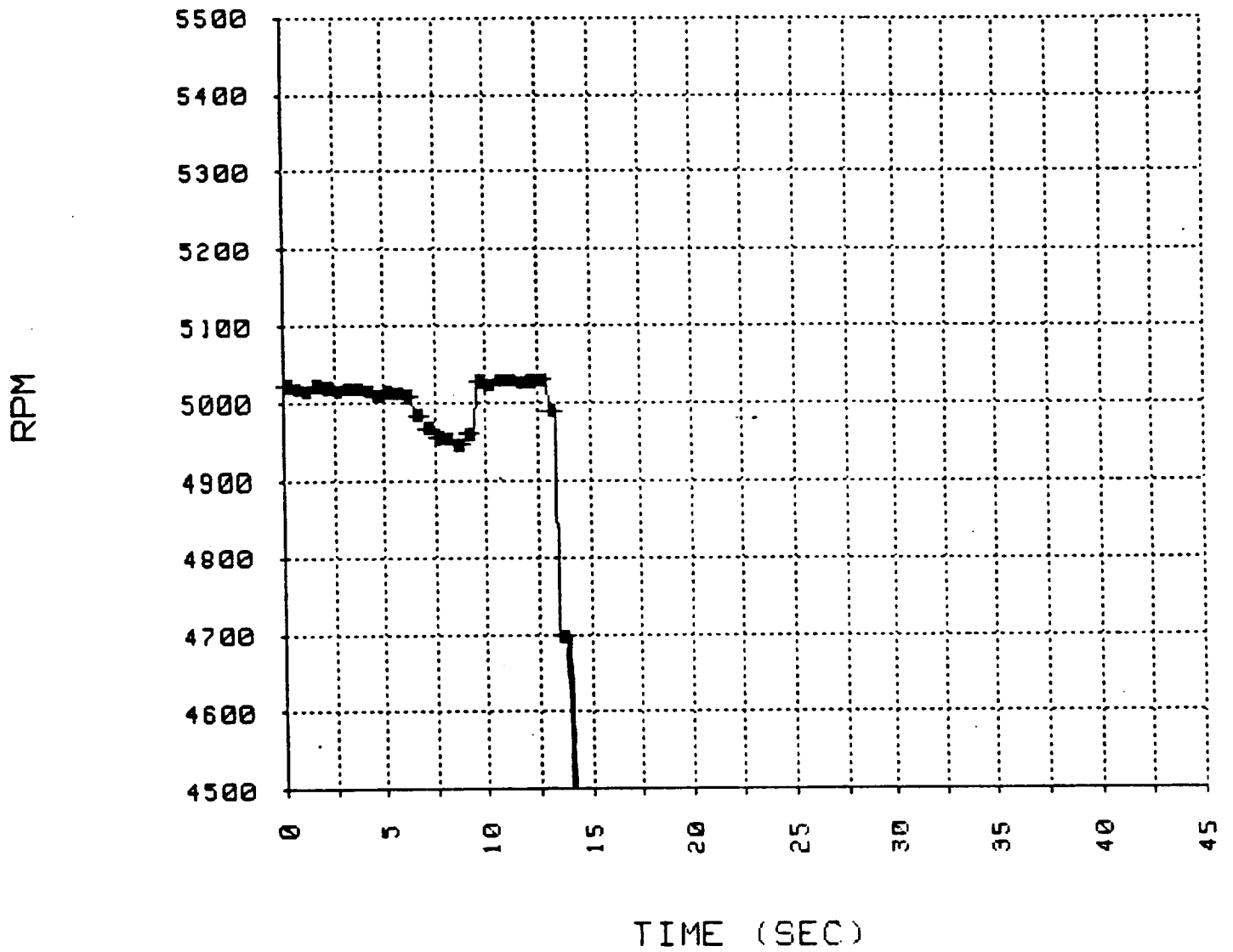


DISPLACEMENT (in)



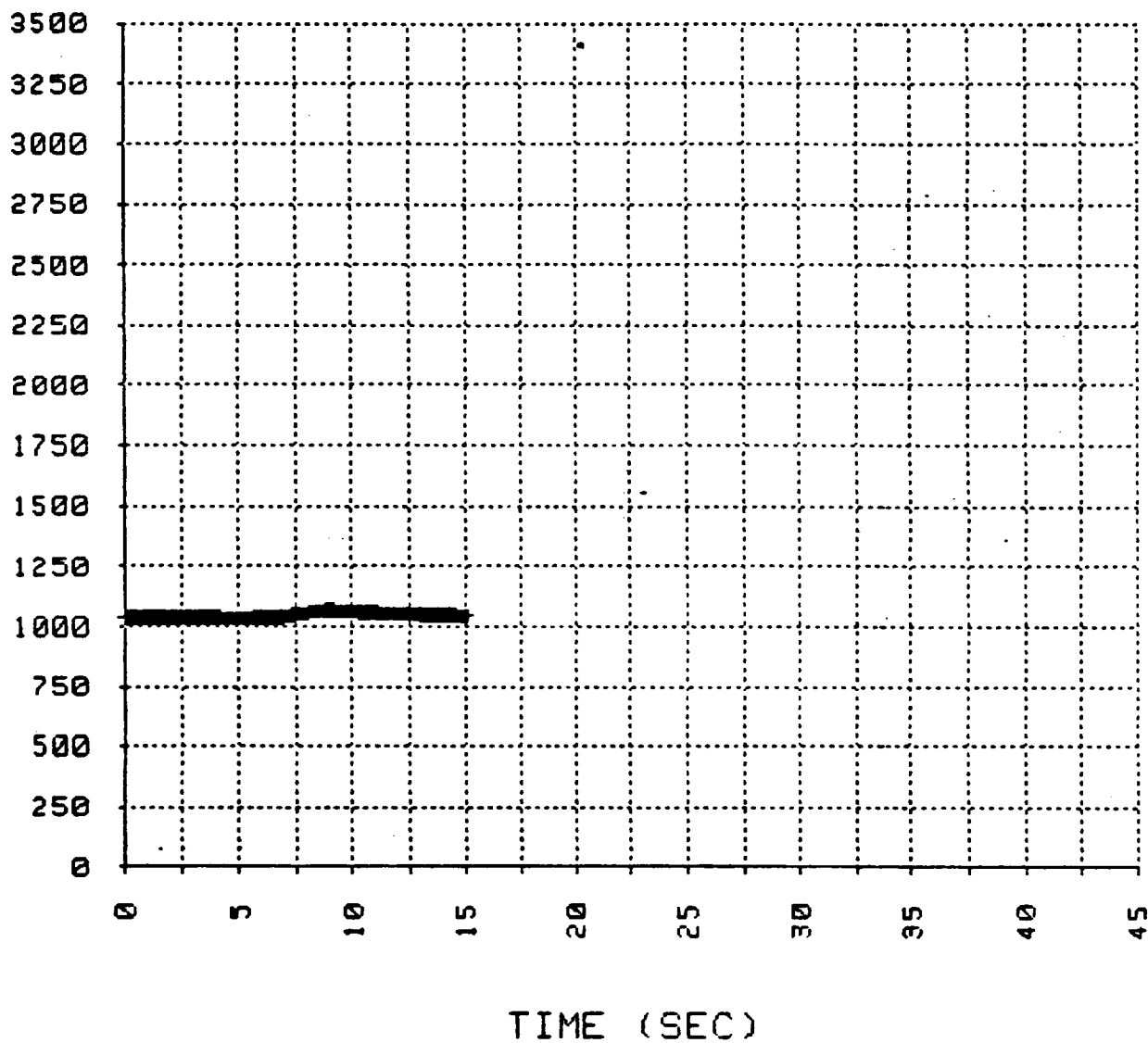


FRT #231 (1000 PSIG GN2)



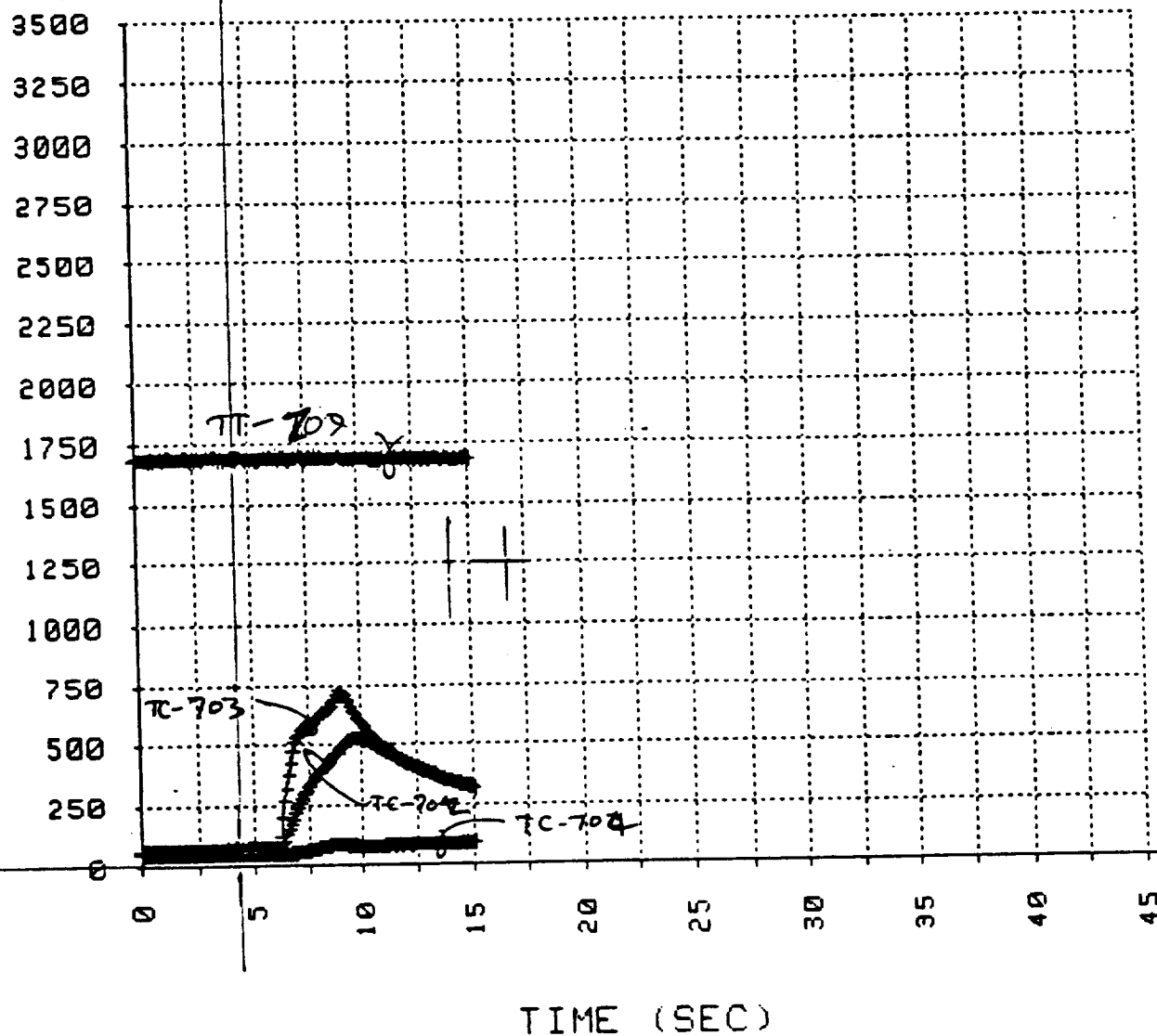
CHAMBER PRESSURE (PSIG)

FRT #231 (1000 PSIG GN2)

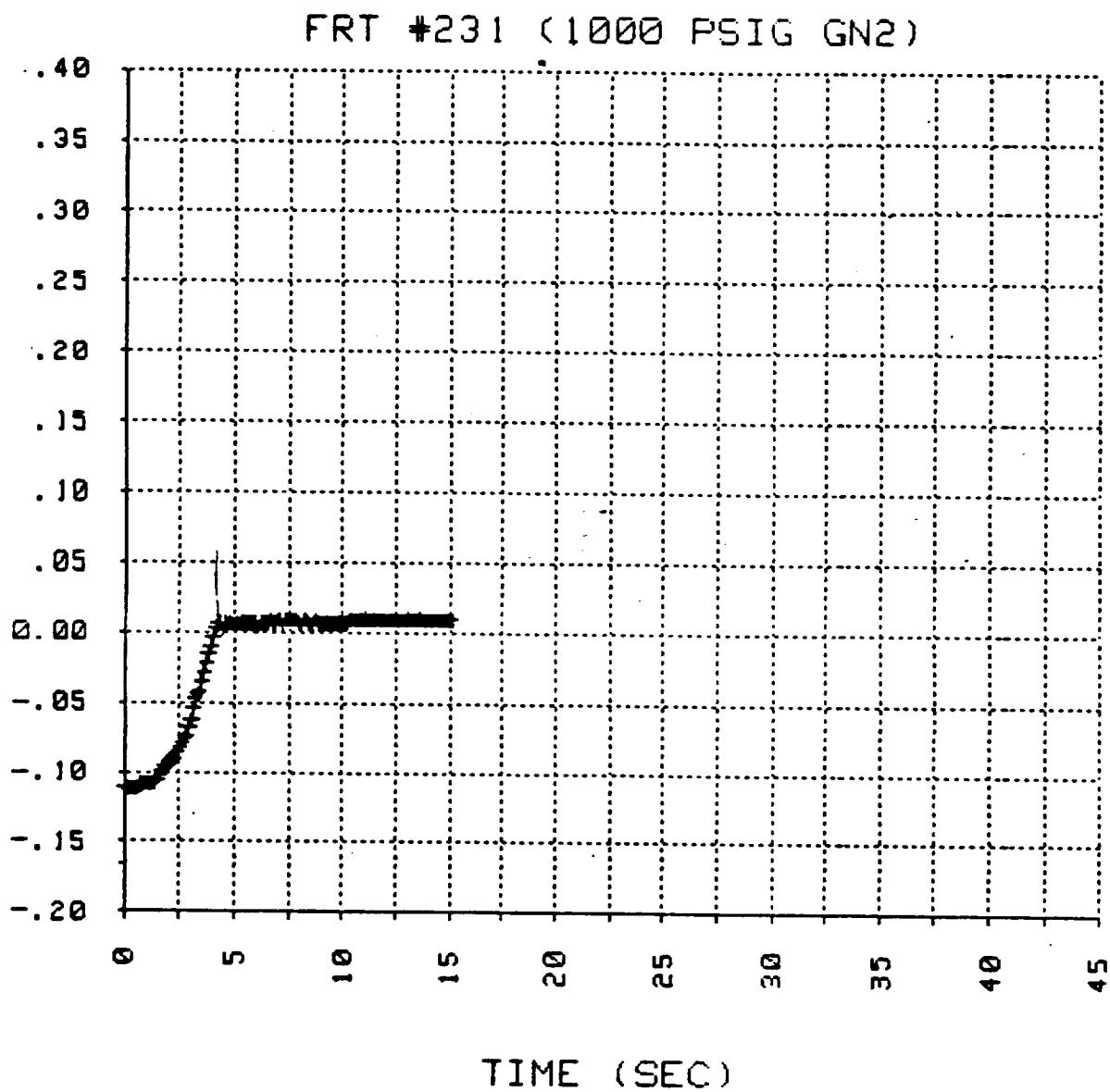


FRT #231 (1000 PSIG GN2)

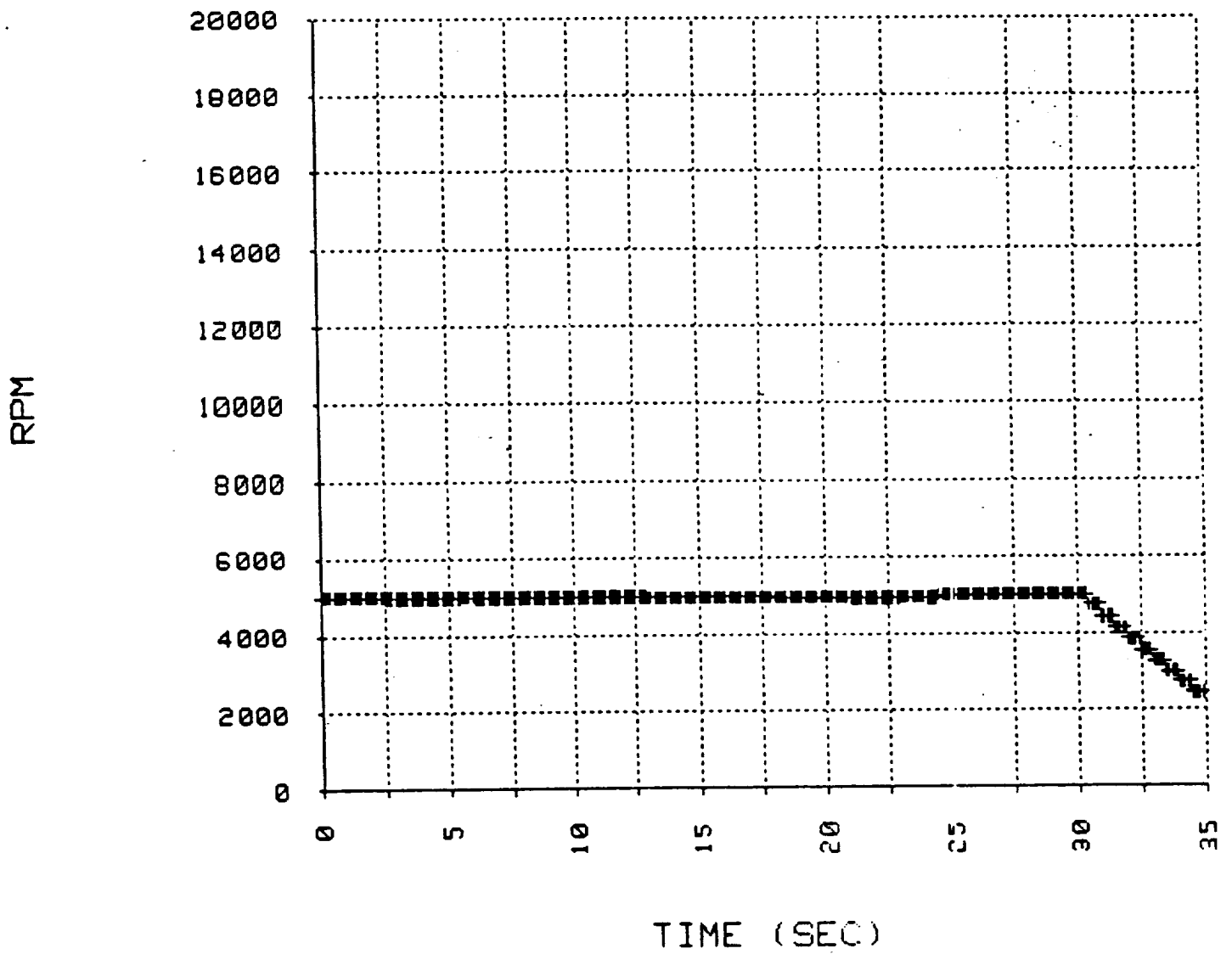
TEMPERATURE (deg F)



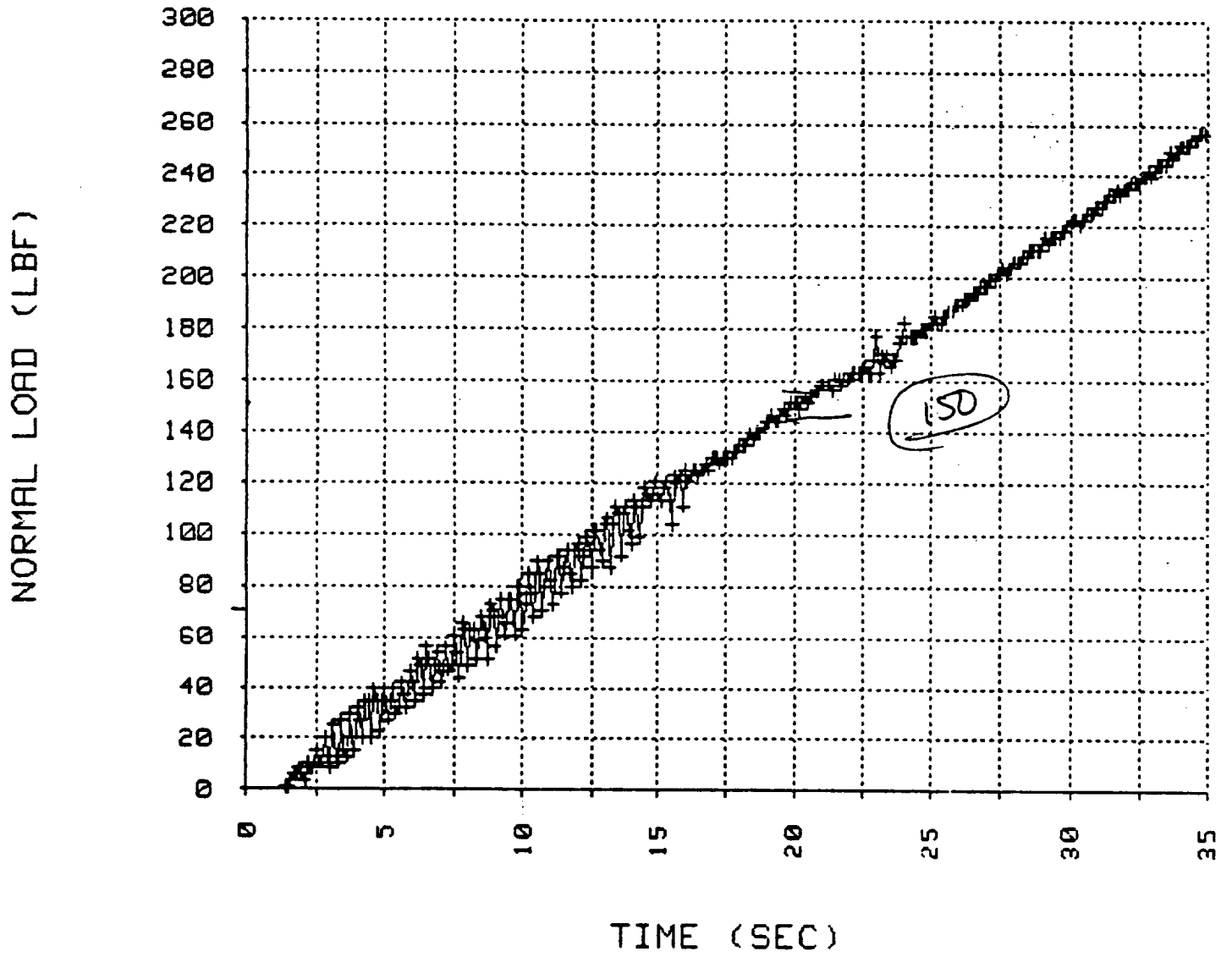
DISPLACEMENT (in)



FRT #212

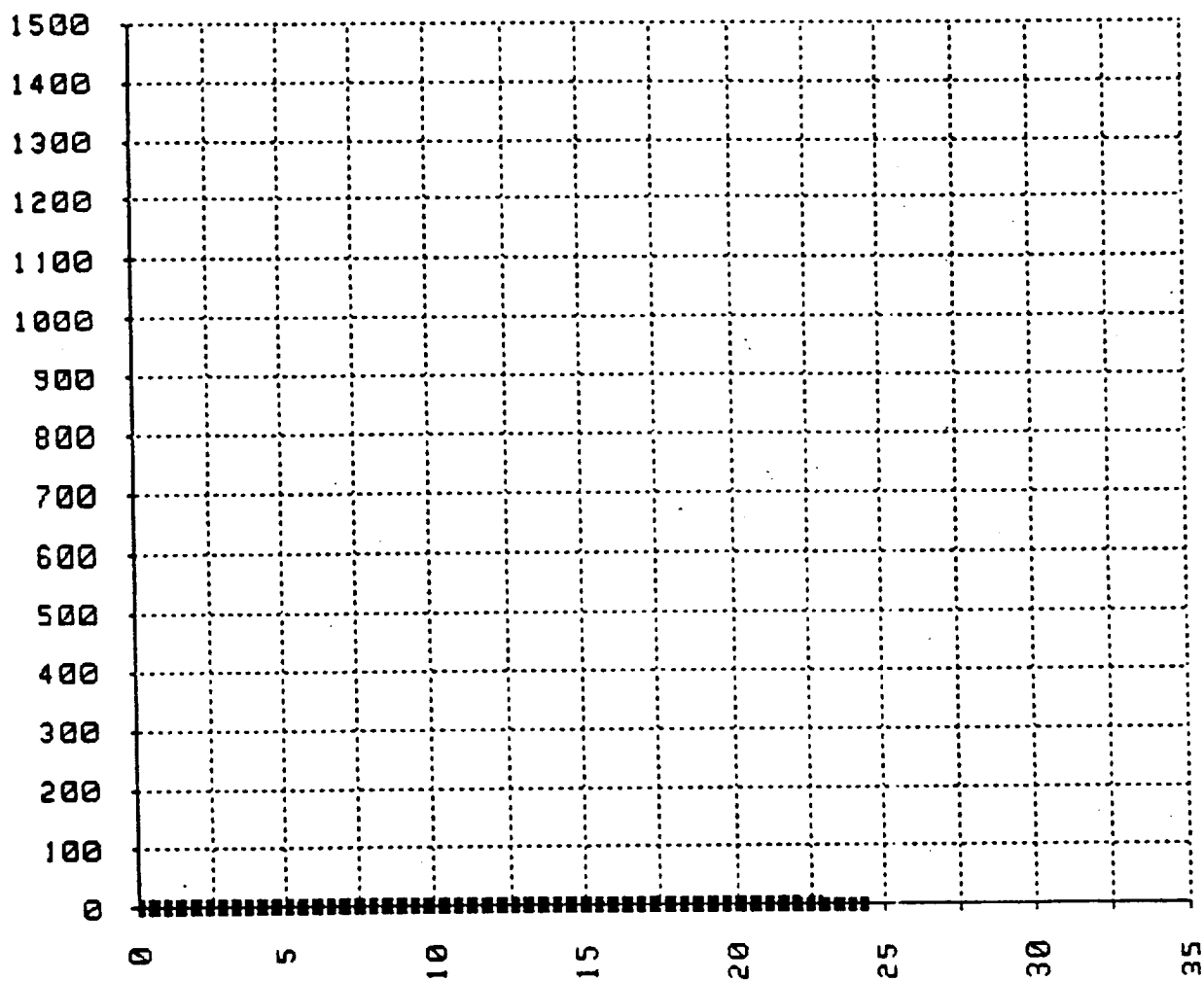


FRT #212

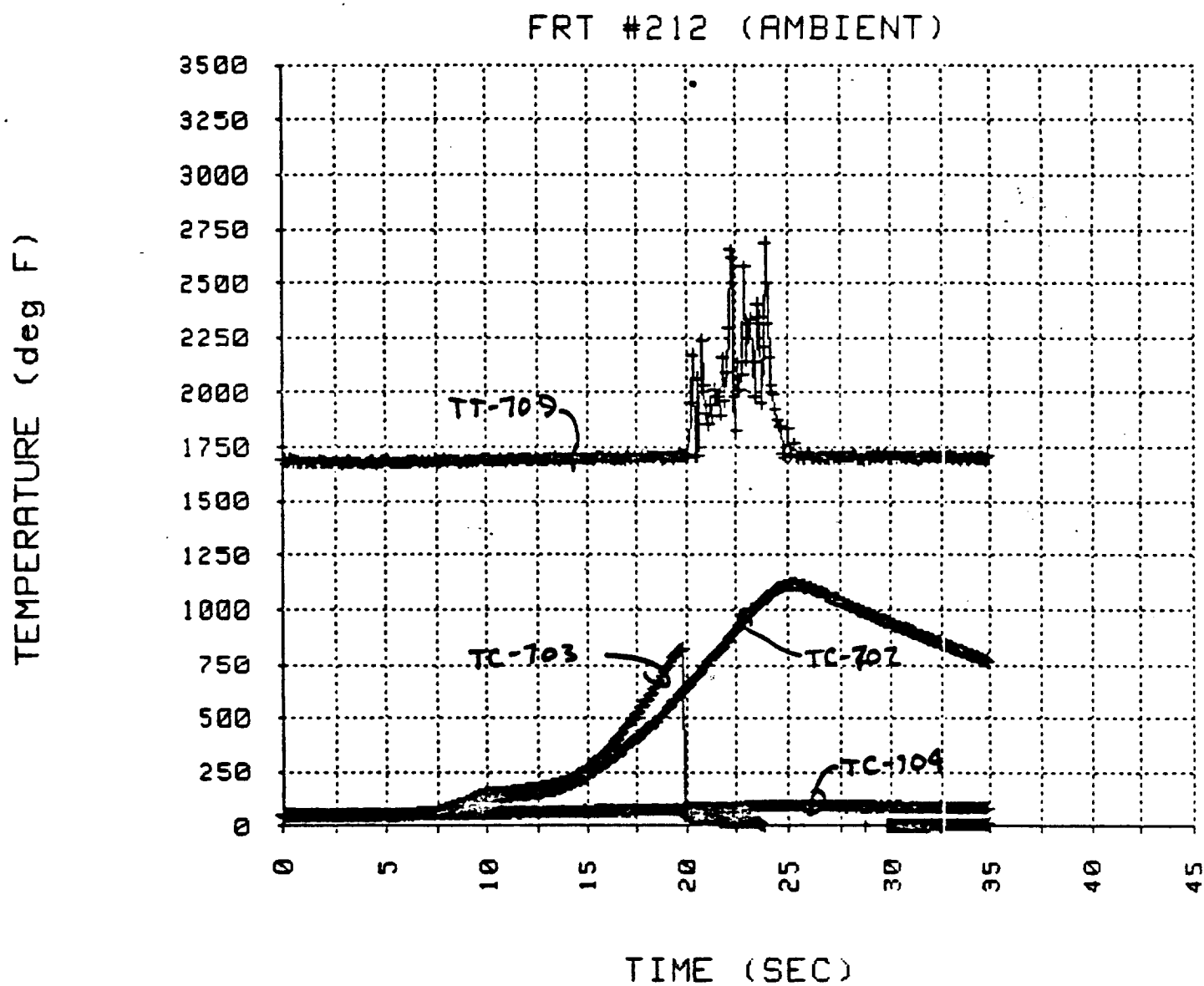


CHAMBER PRESSURE (PSIG)

FRT #212

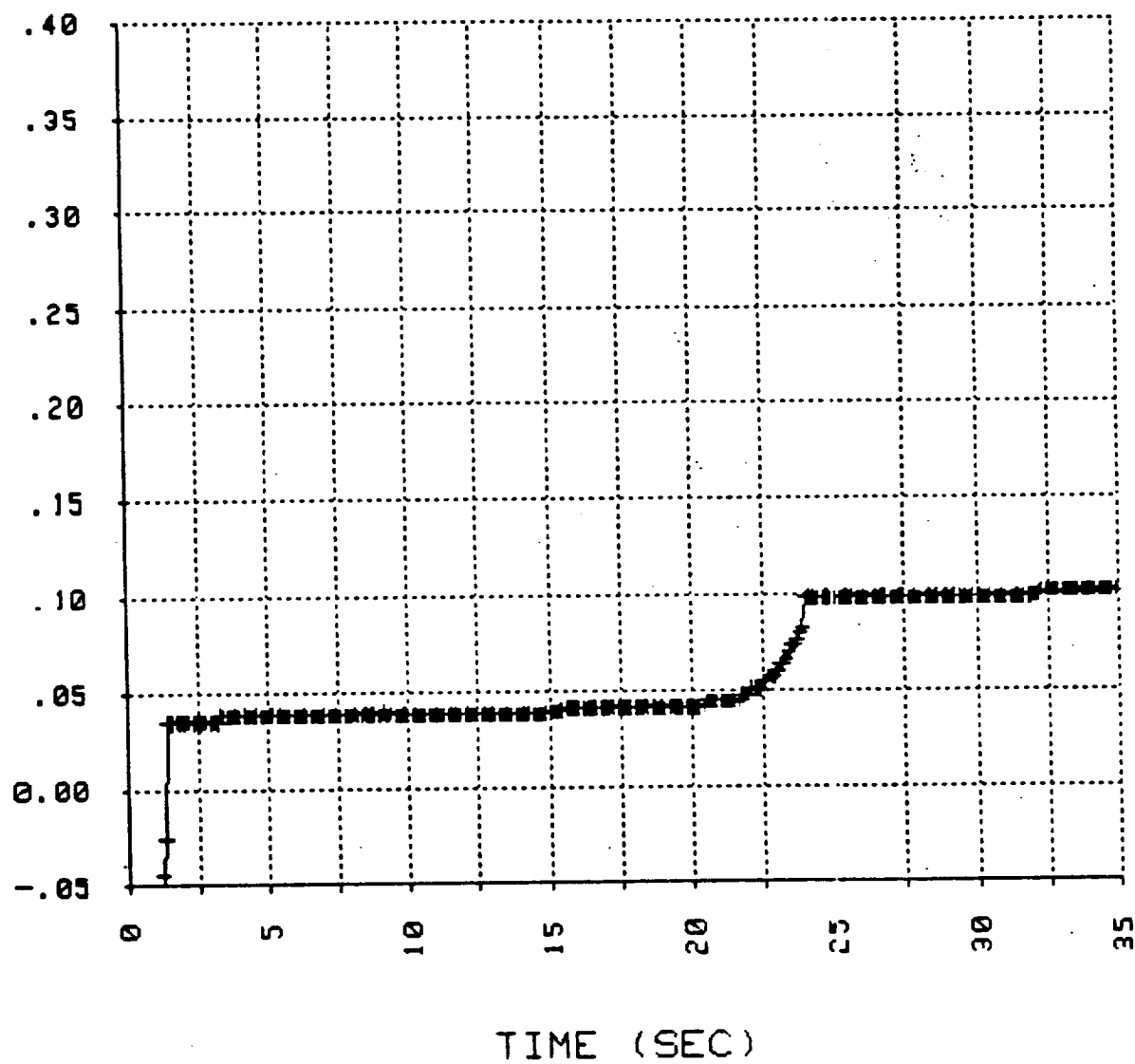


TIME (SEC)

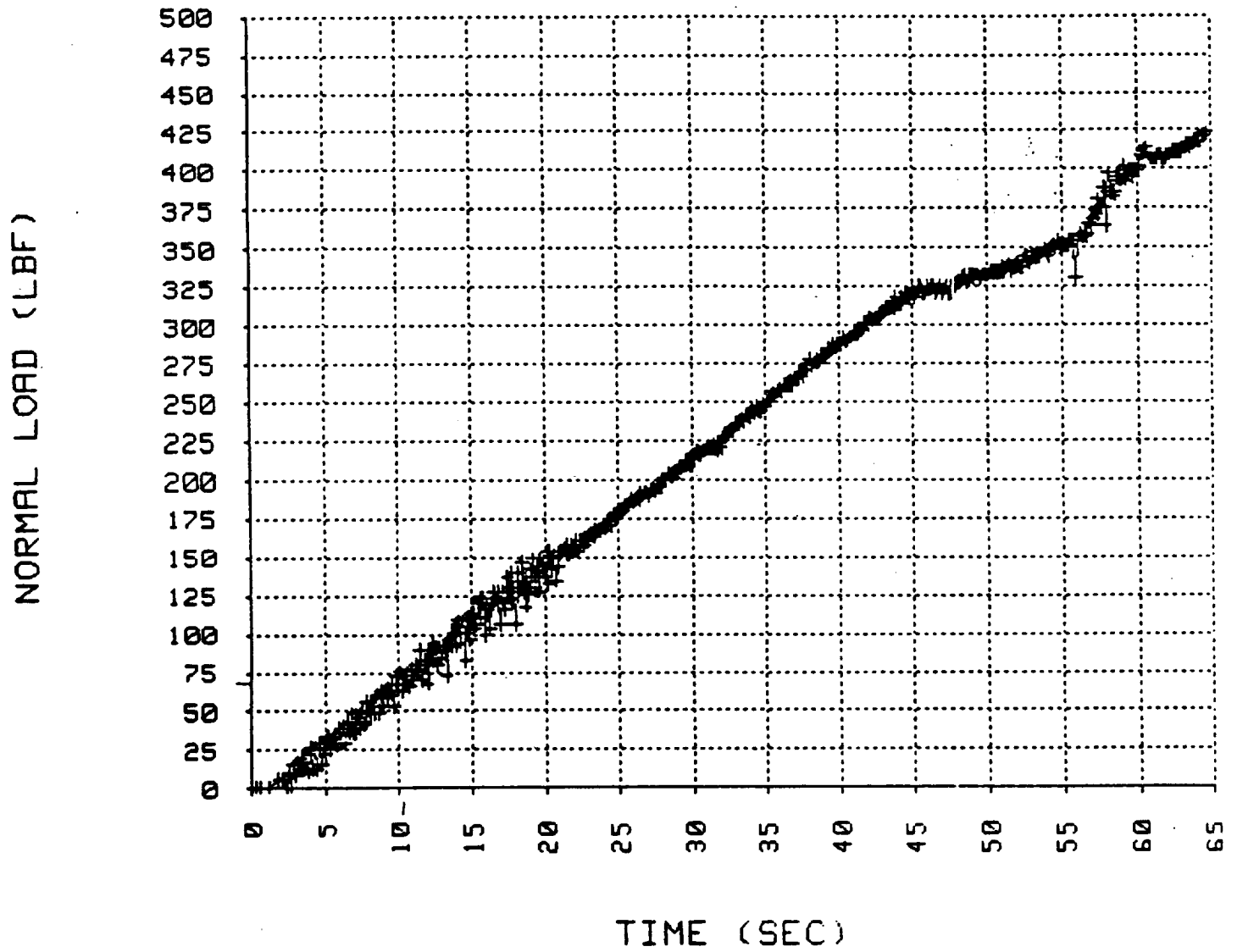


FRT #212

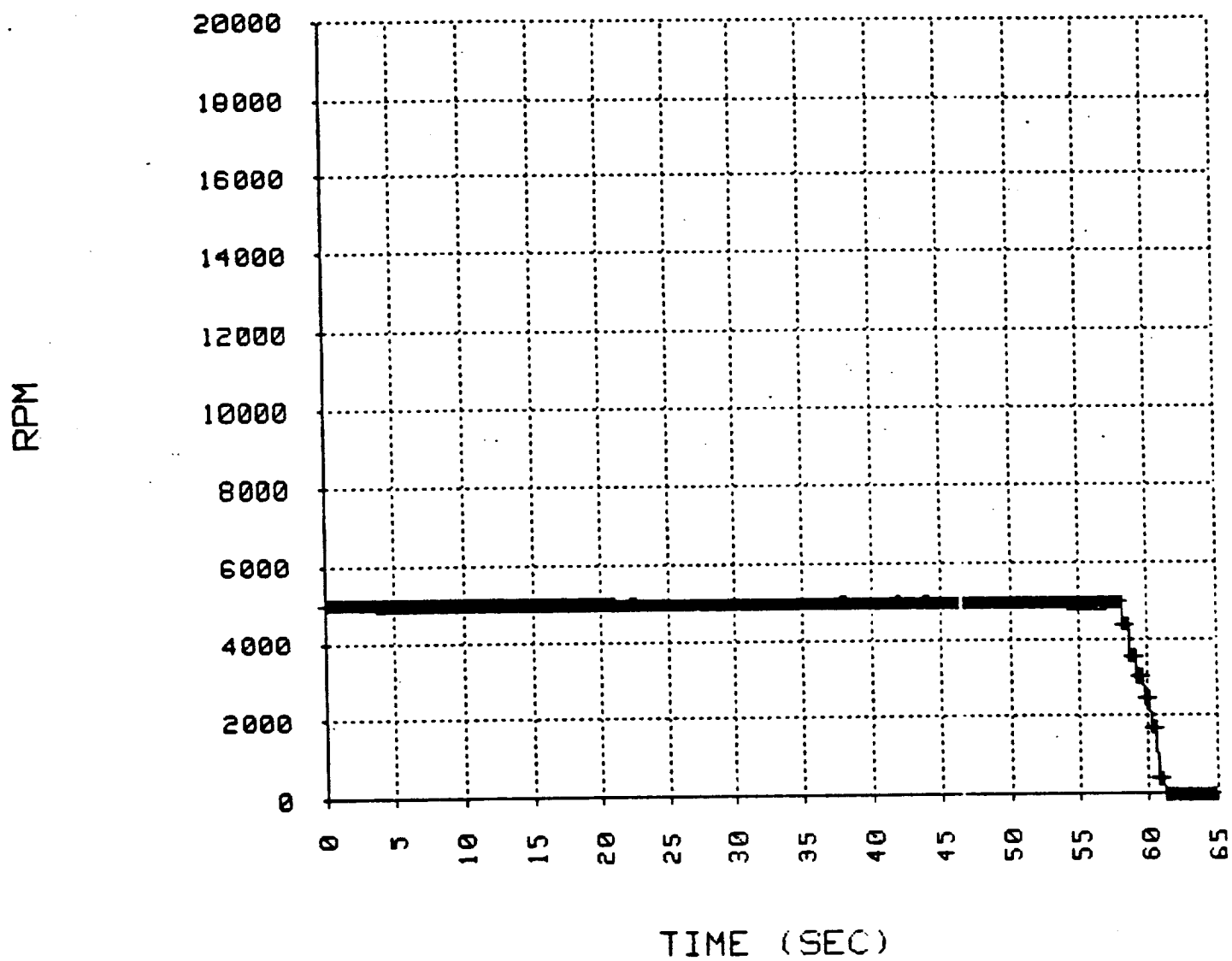
DISPLACEMENT (in)



FRT #213

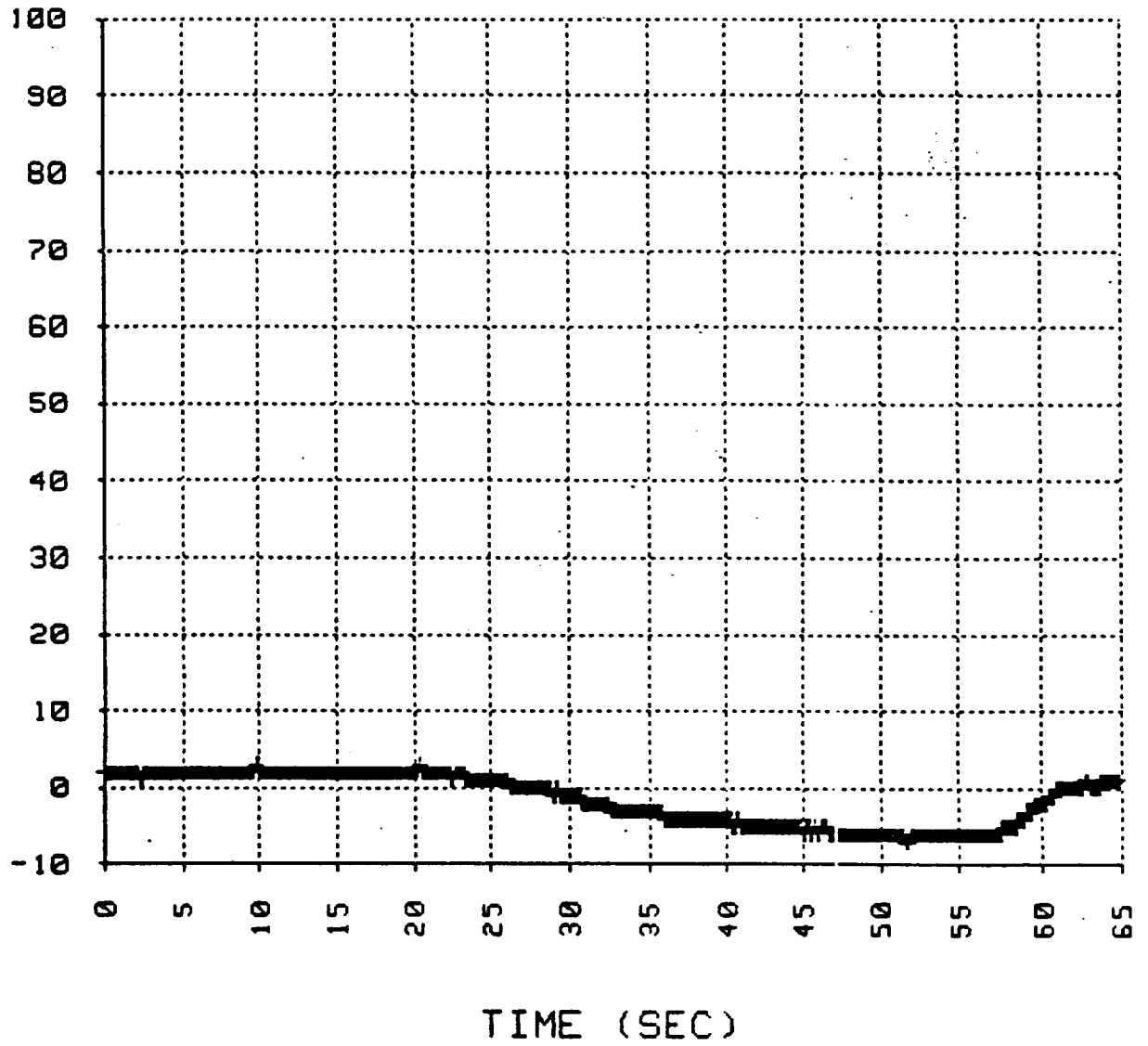


FRT #213

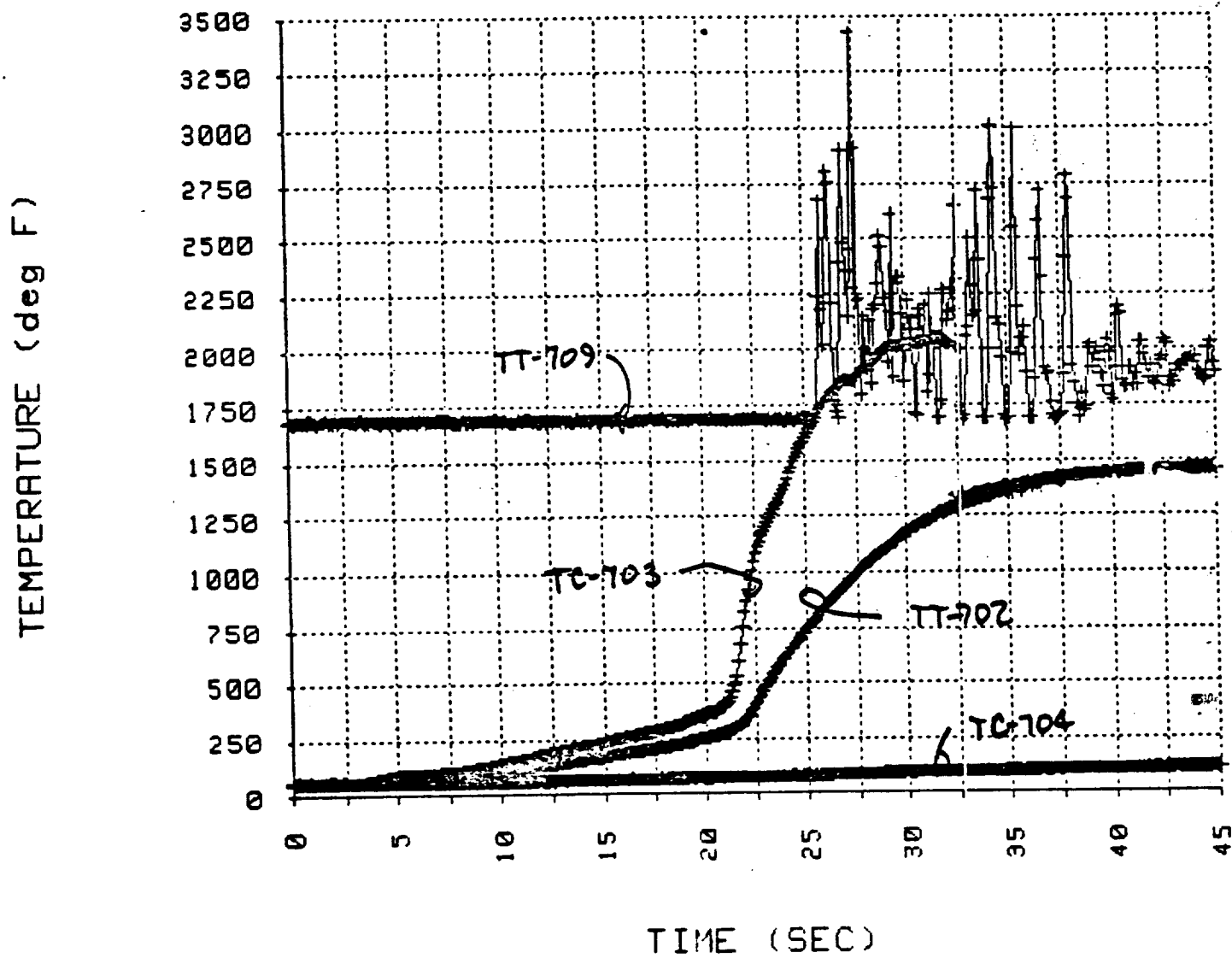


FRT #213

CHAMBER PRESSURE (PSIG)

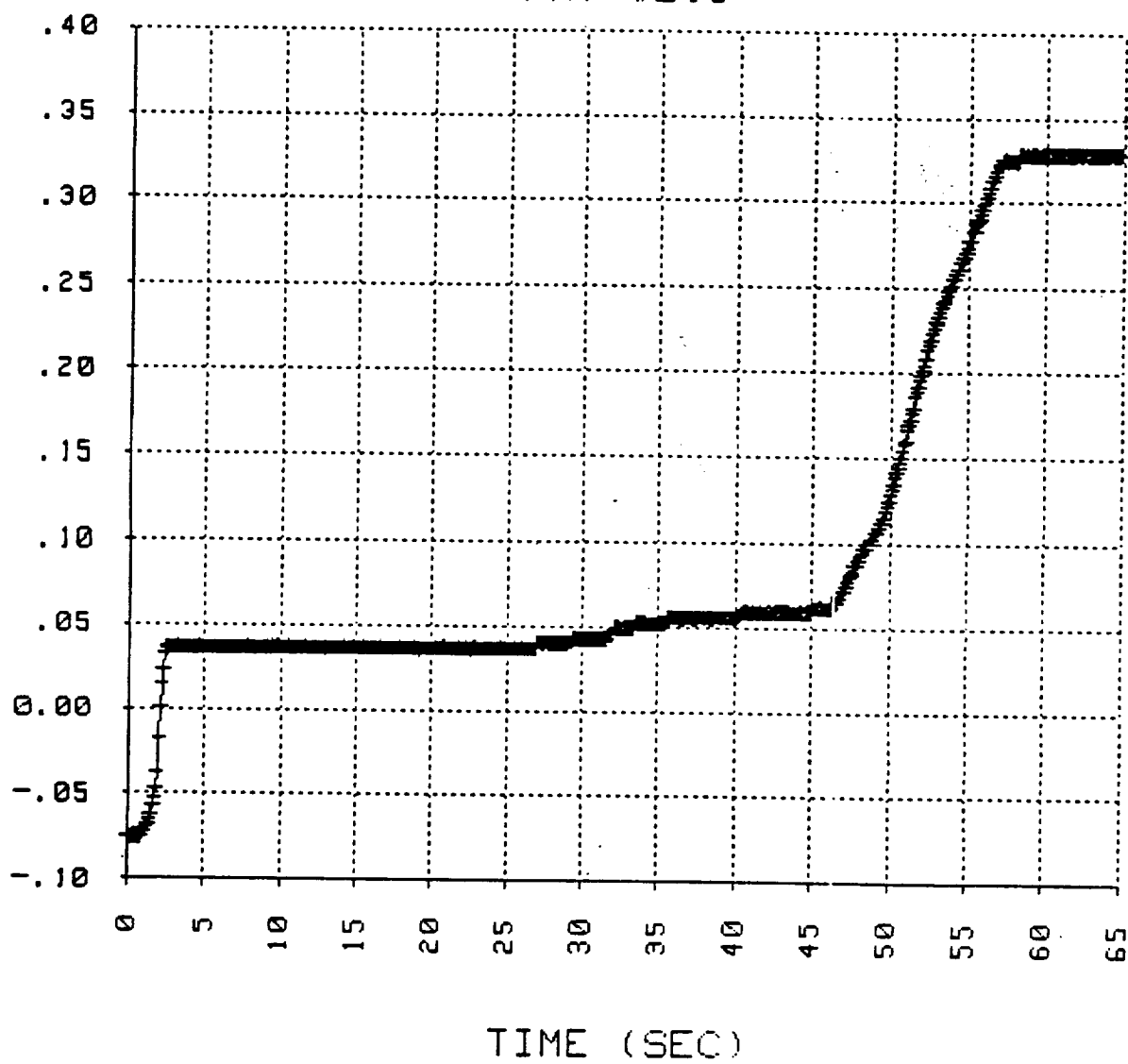


FRT #213 (AMBIENT)

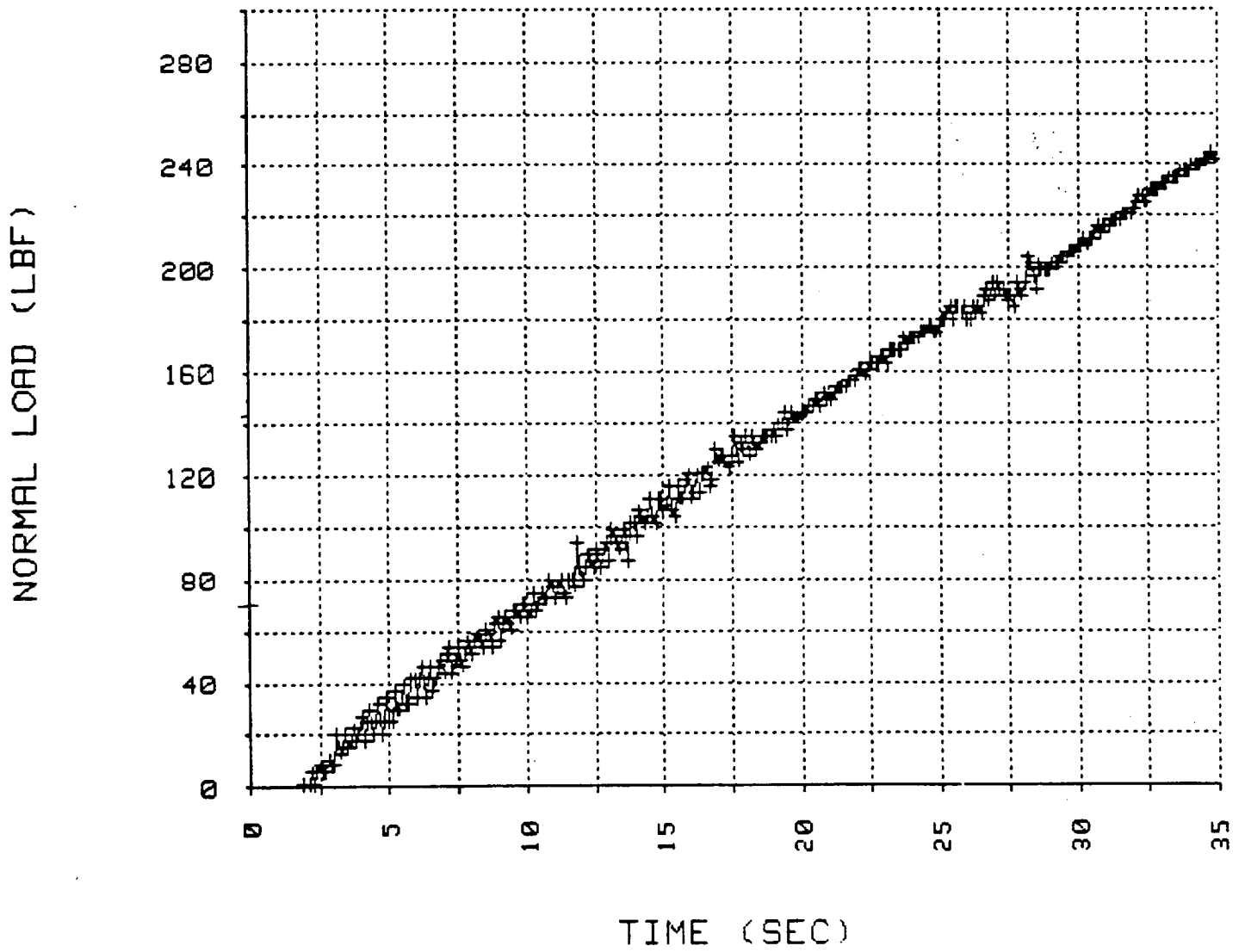


DISPLACEMENT (in)

FRT #213

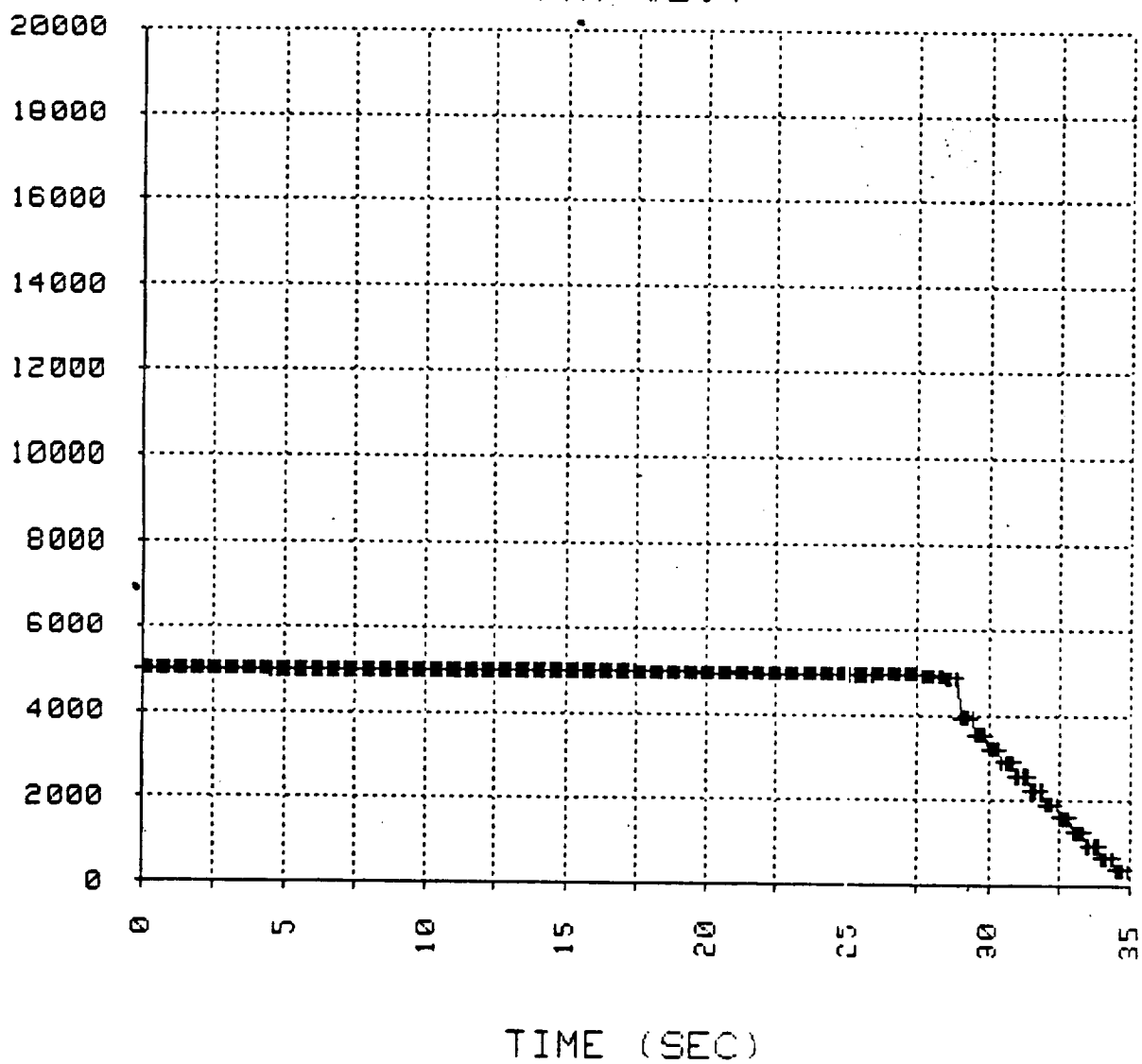


FRT #214



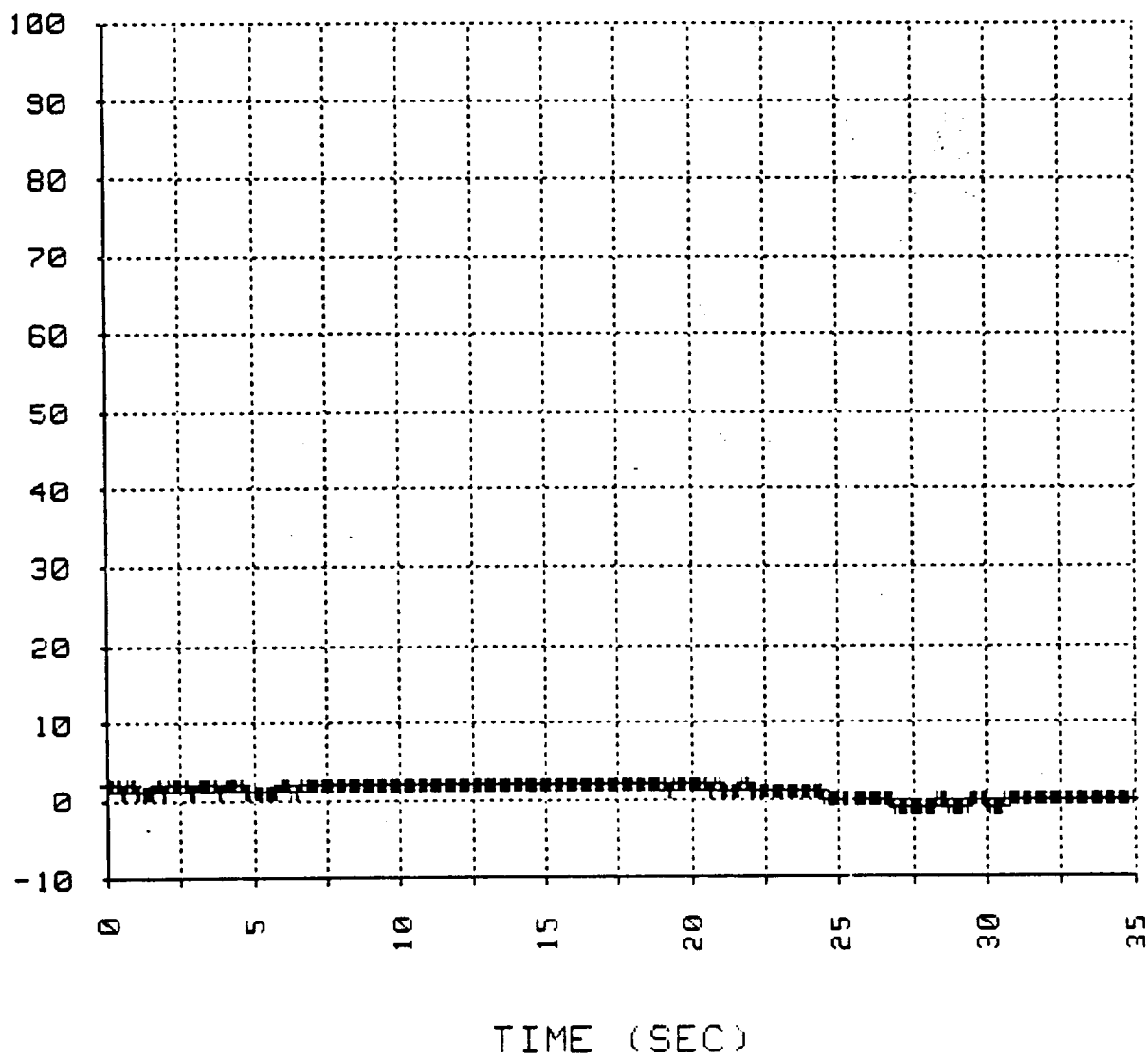
RPM

FRT #214



CHAMBER PRESSURE (PSIG)

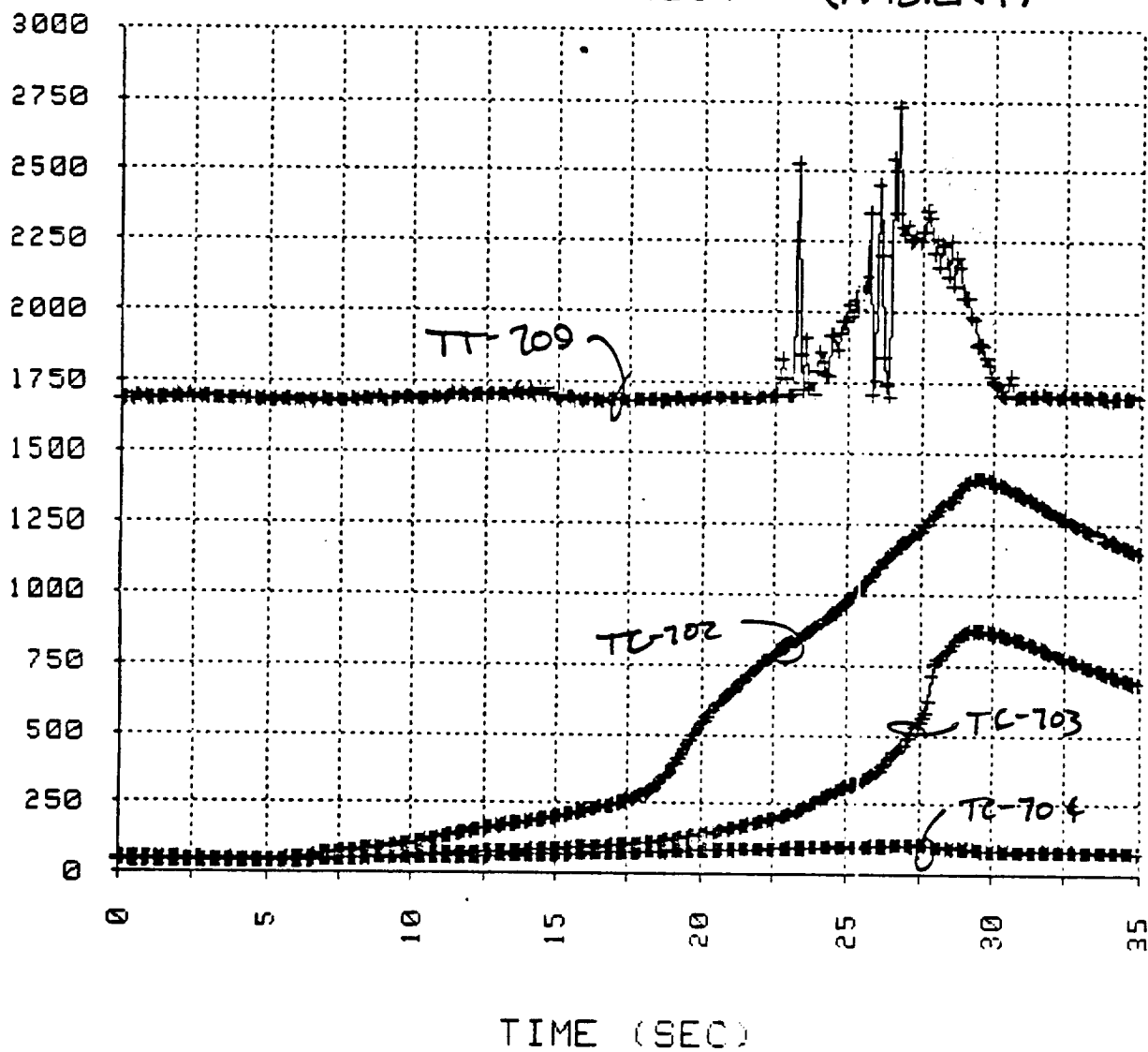
FRT #214



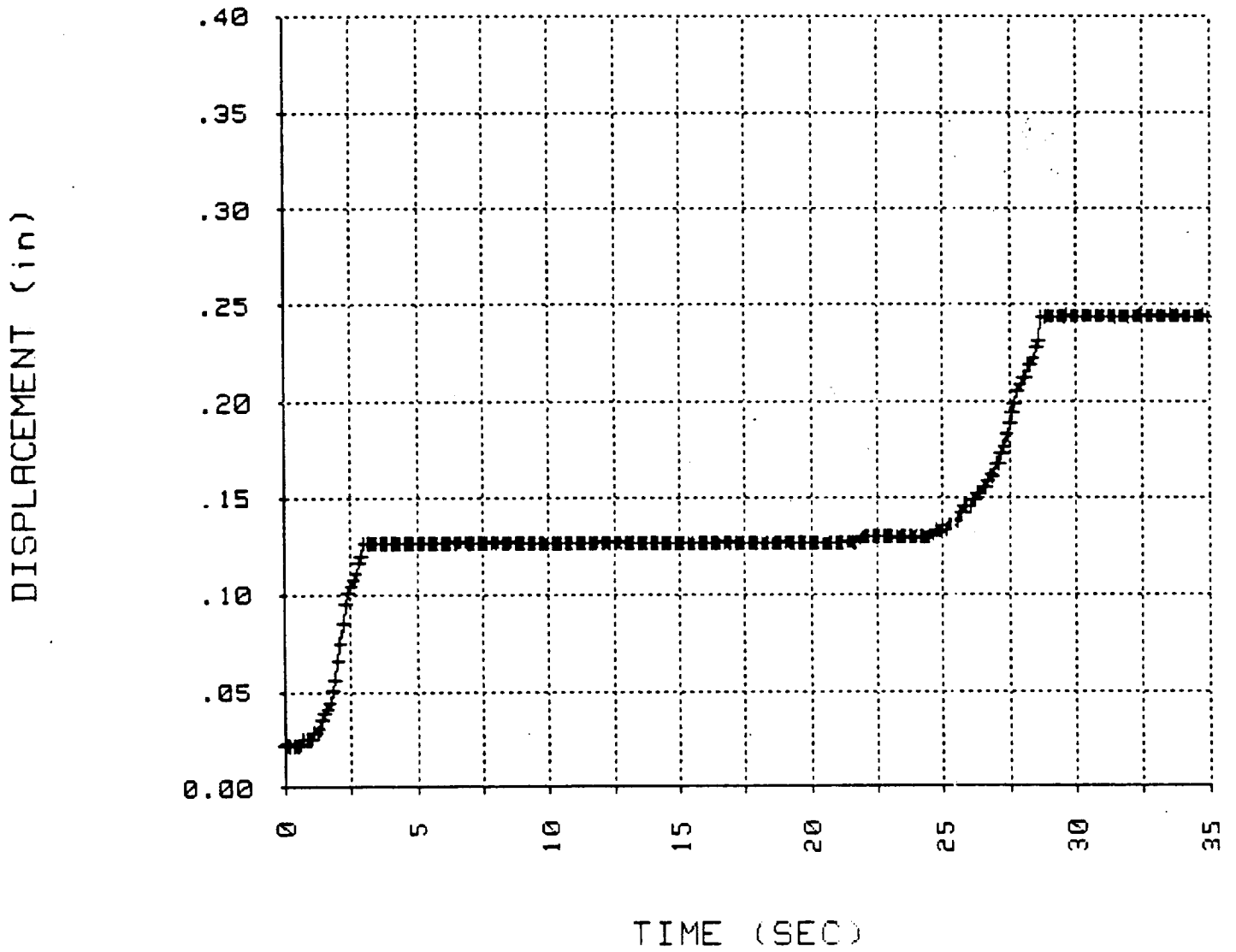
F-120

TEMPERATURE (deg F)

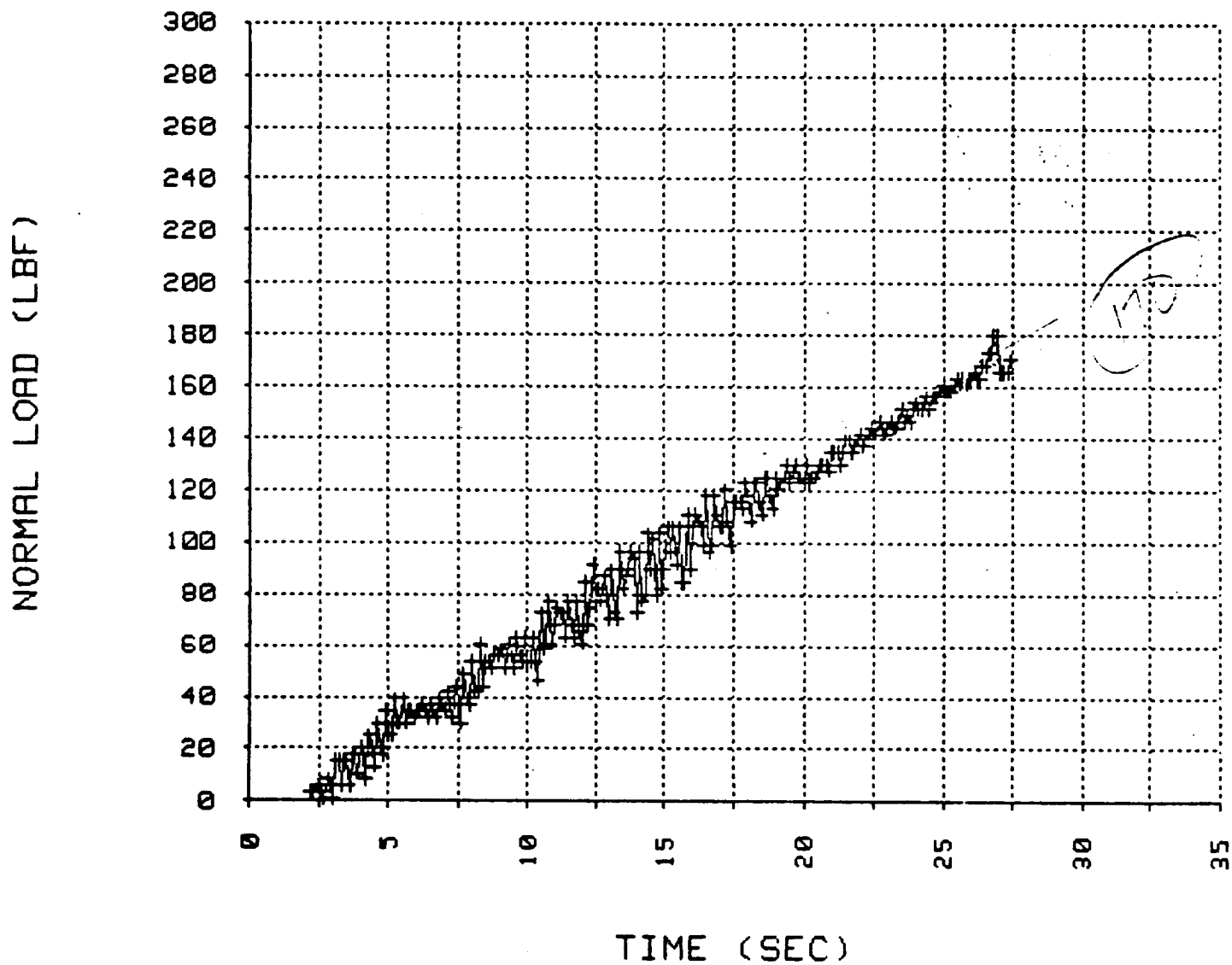
FRT #214 (AMBIENT)

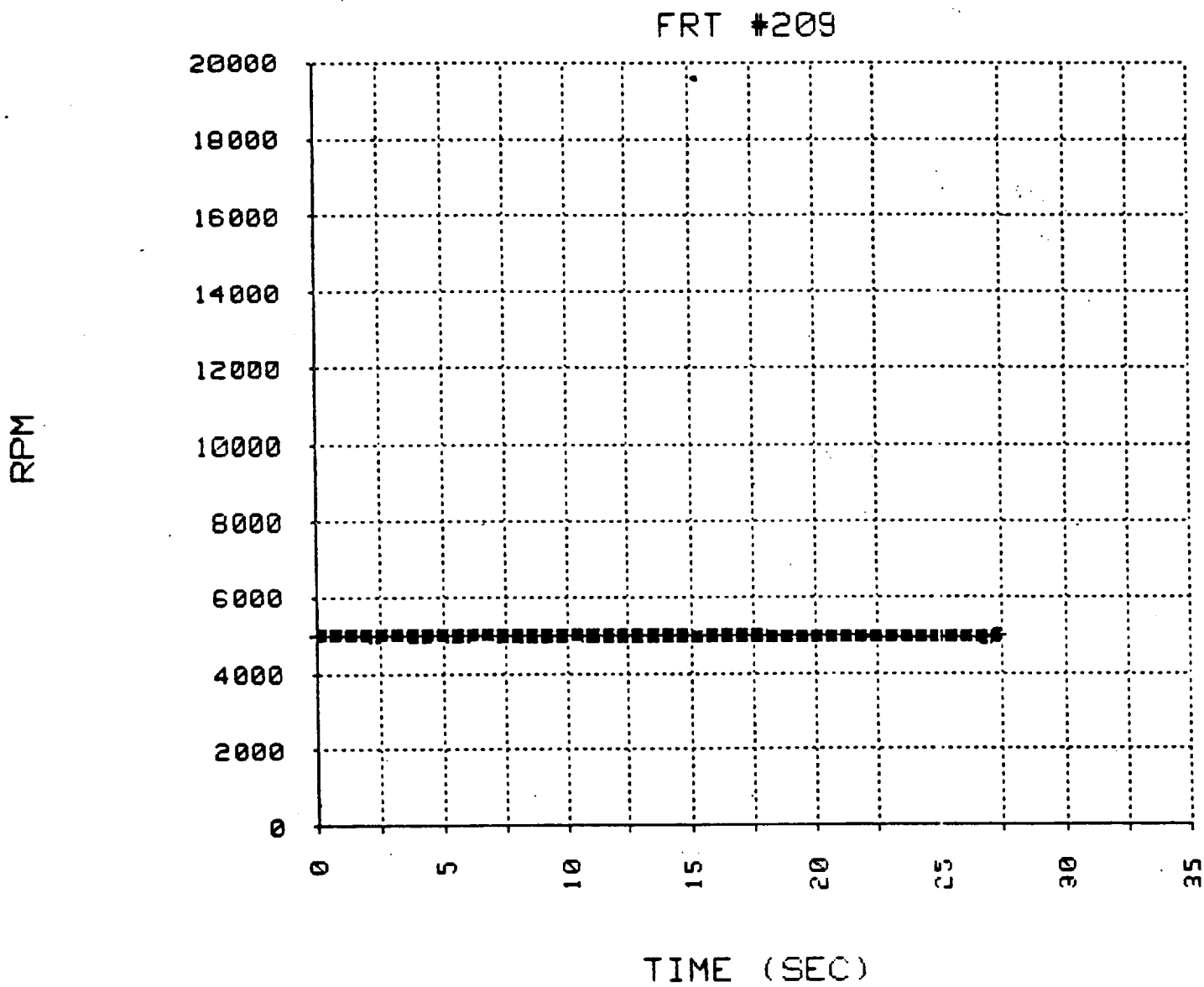


FRT #214



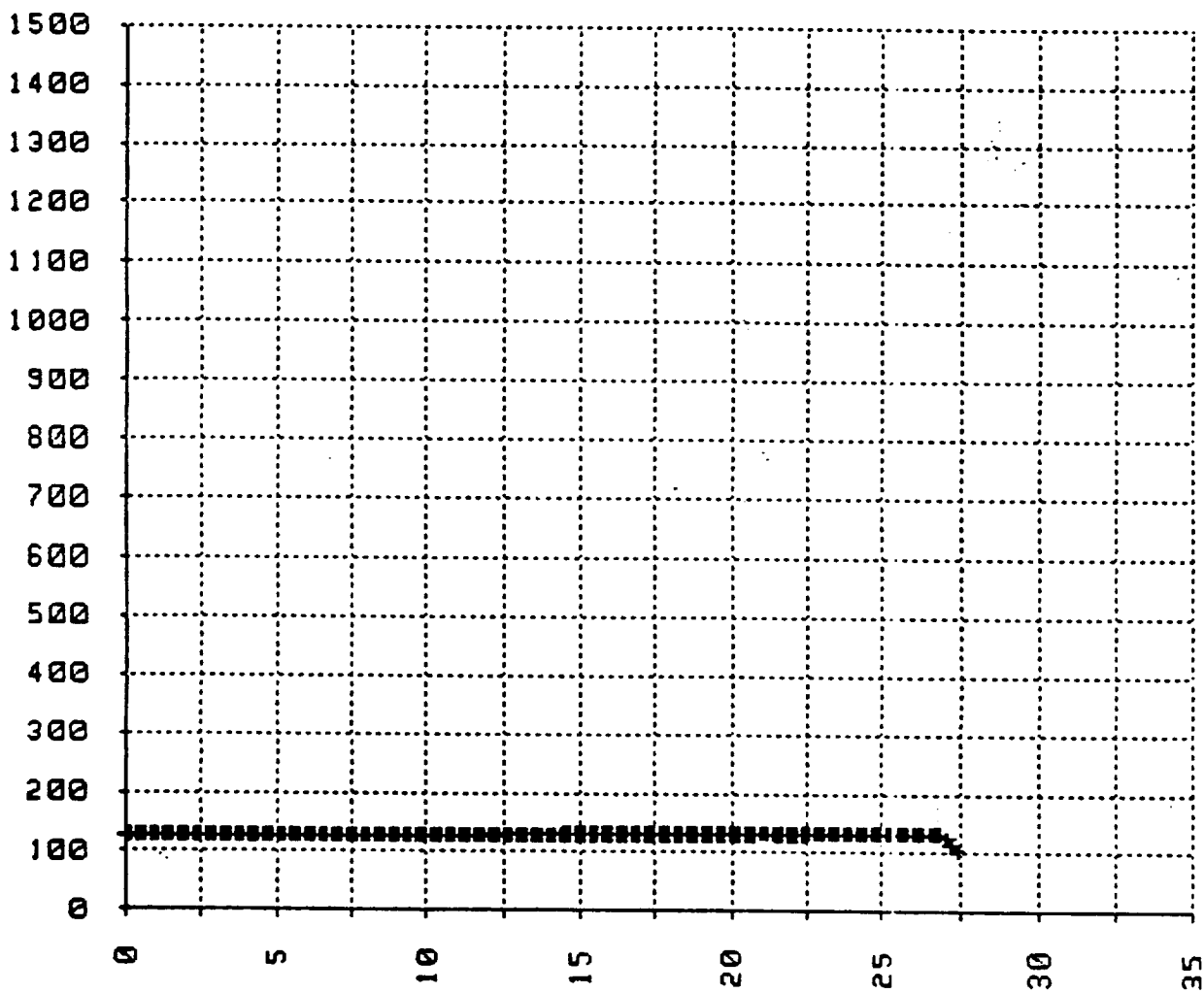
FRT #209





FRT #209

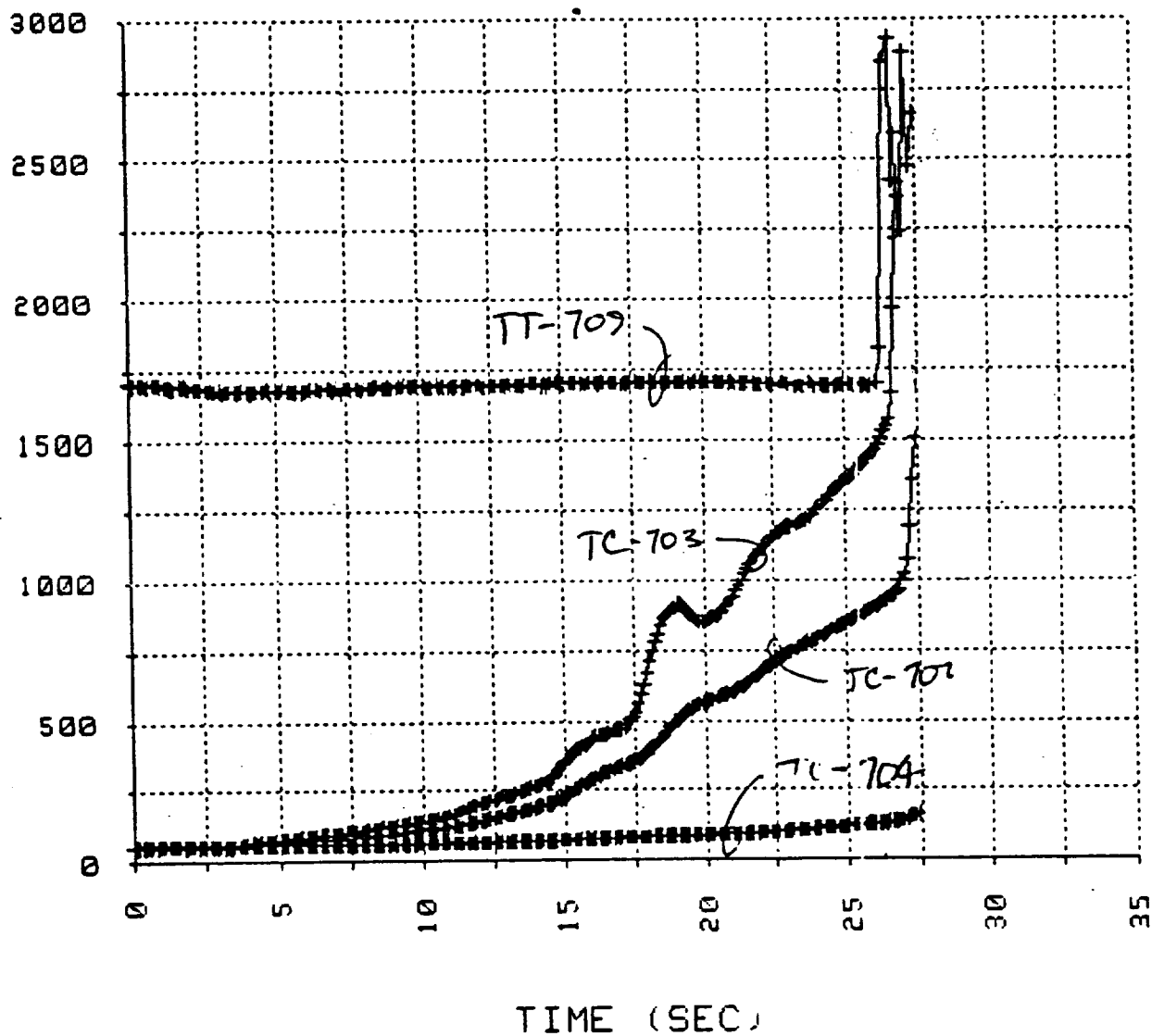
CHAMBER PRESSURE (PSIG)



TIME (SEC)

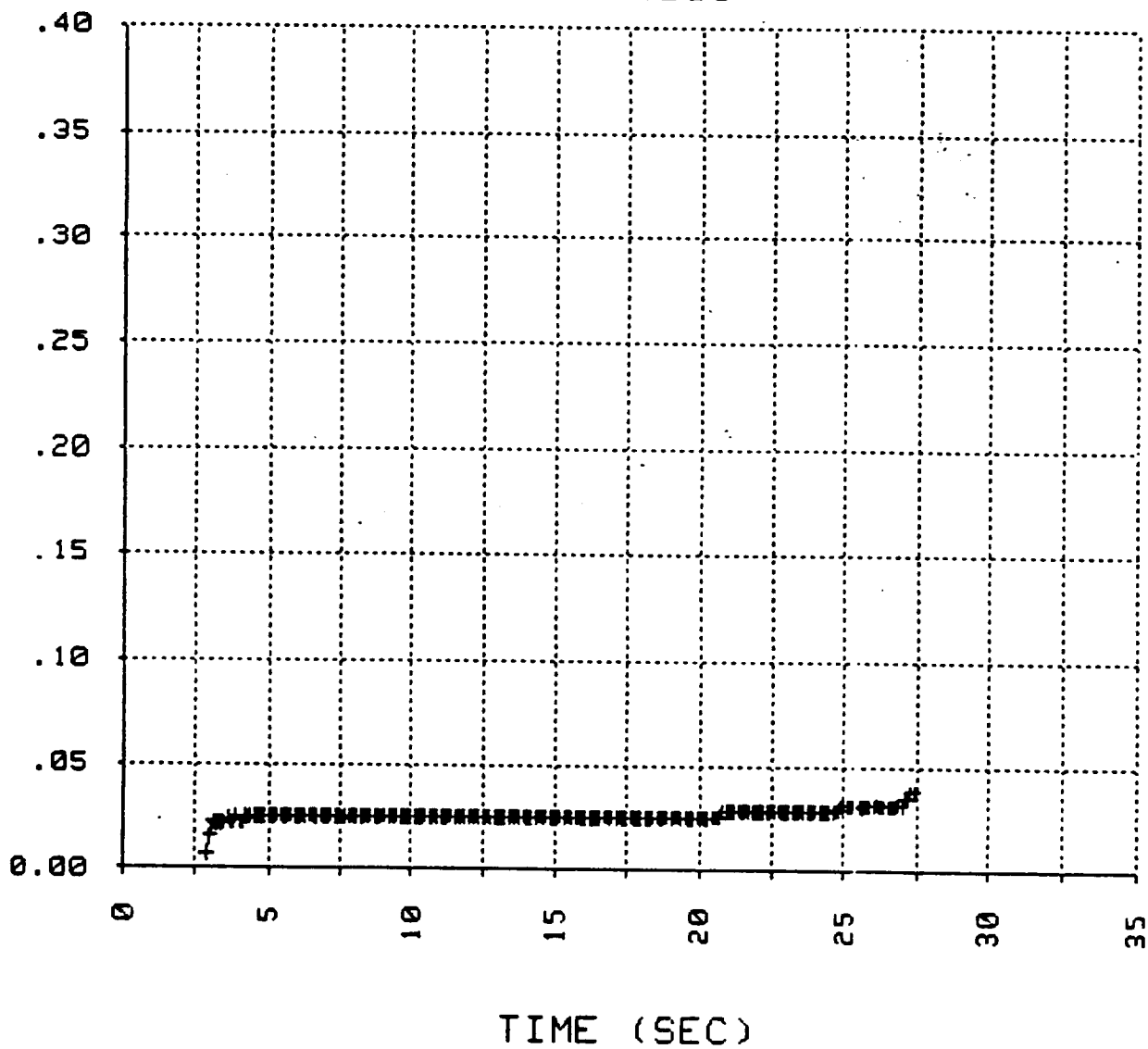
TEMPERATURE (deg F)

FRT #209 (100 PSIG)

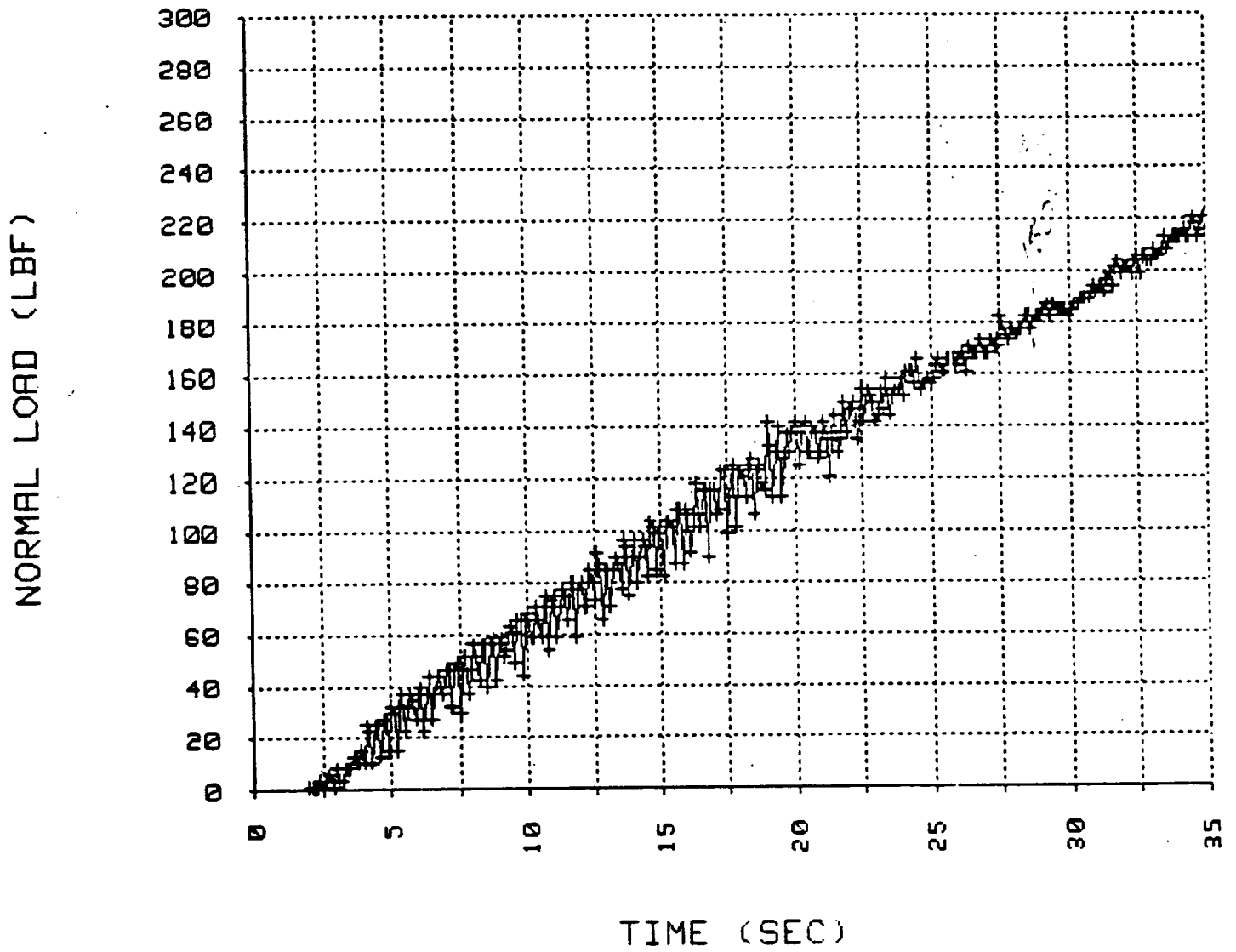


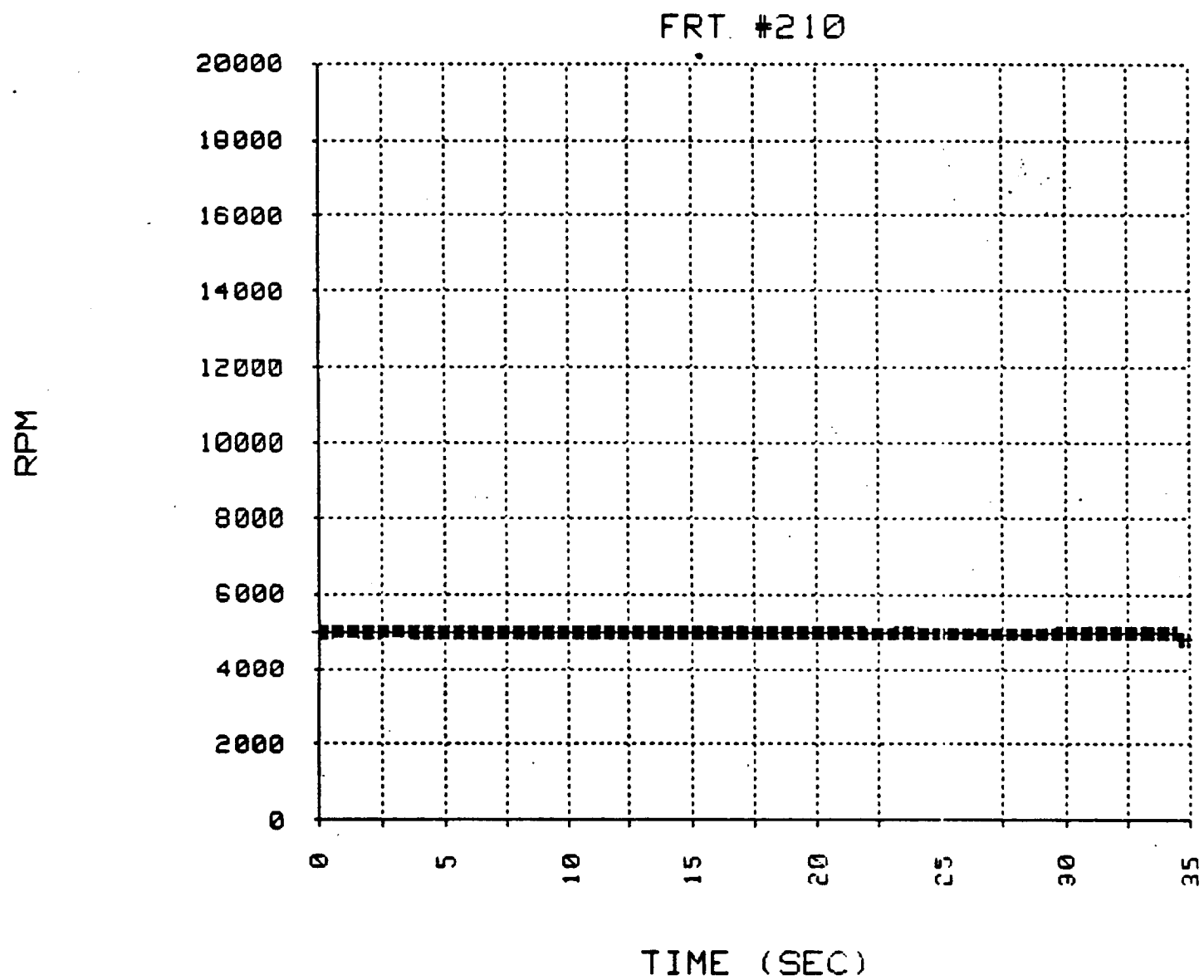
DISPLACEMENT (in)

FRT #209



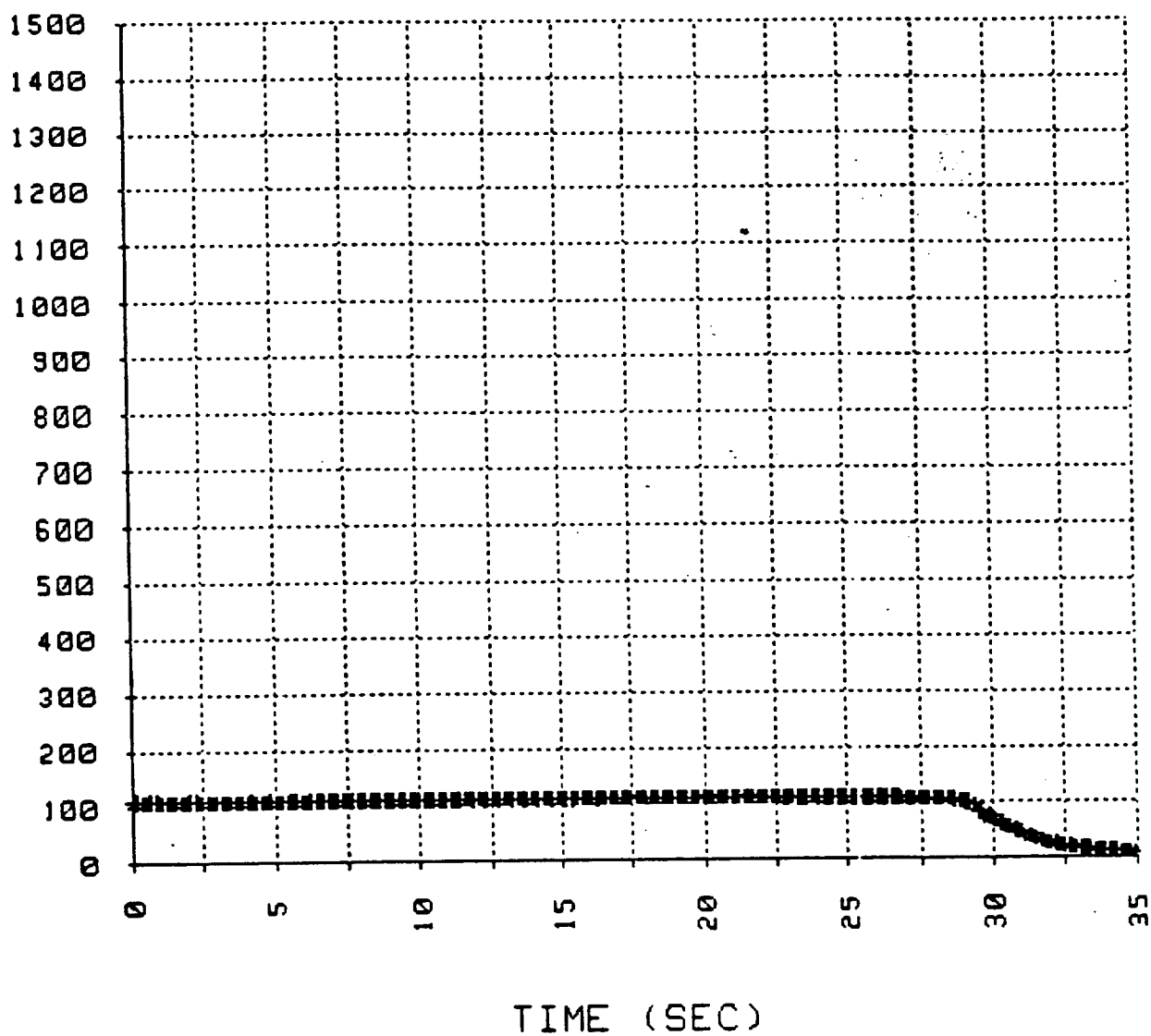
FRT #210





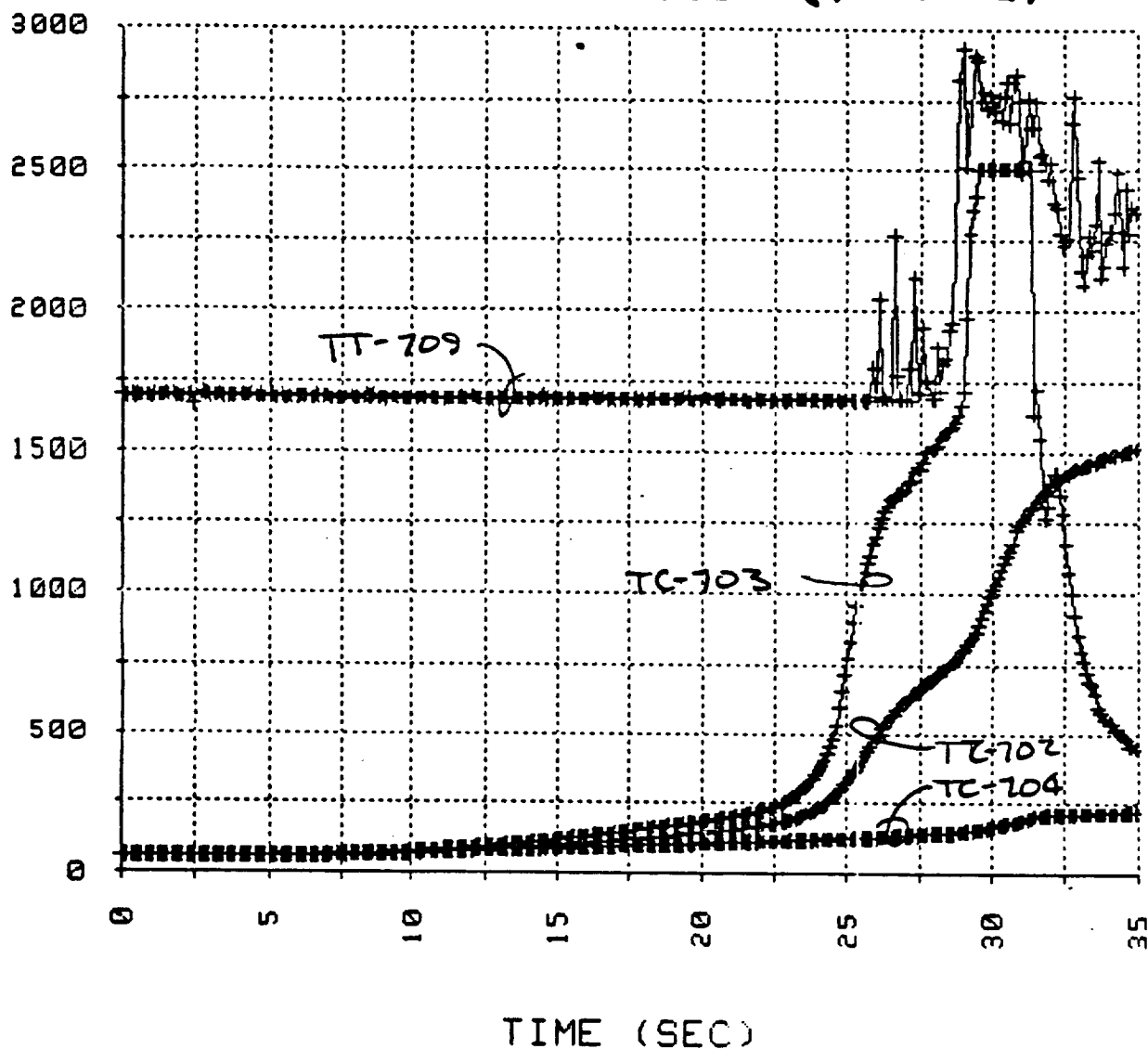
CHAMBER PRESSURE (PSIG)

FRT #210



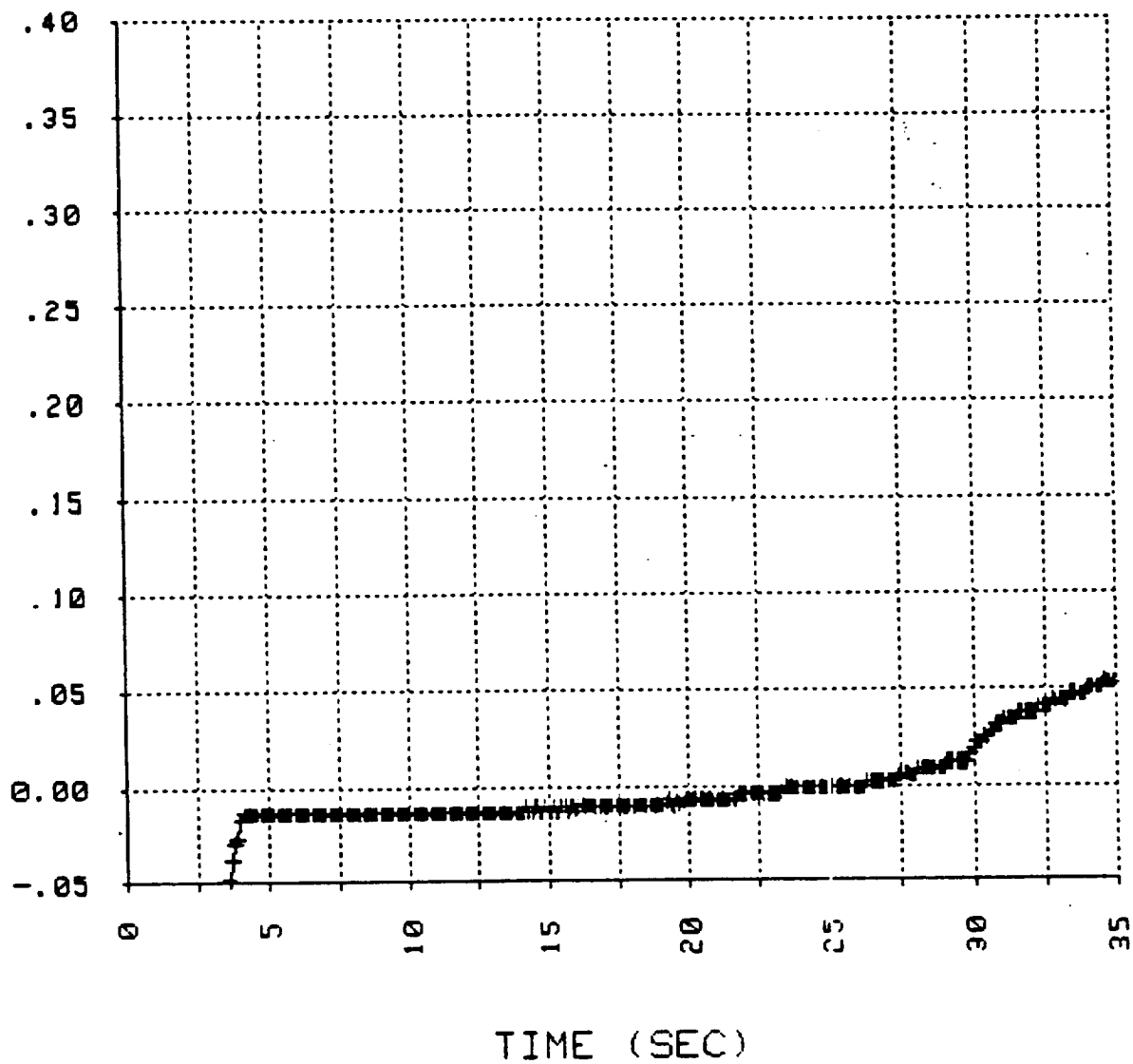
TEMPERATURE (deg F)

FRT #210 (100 PSIG)



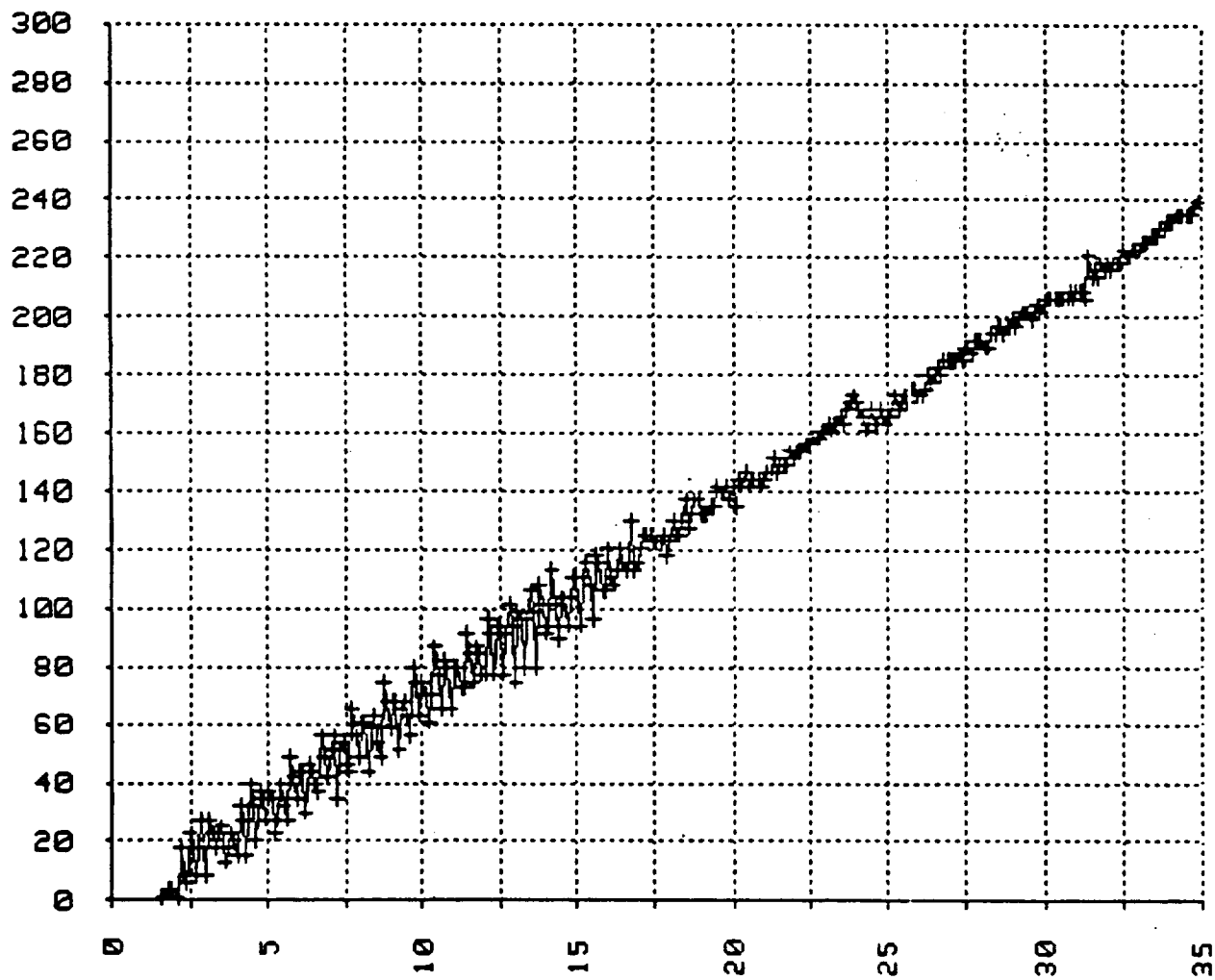
DISPLACEMENT (in)

FRT #210



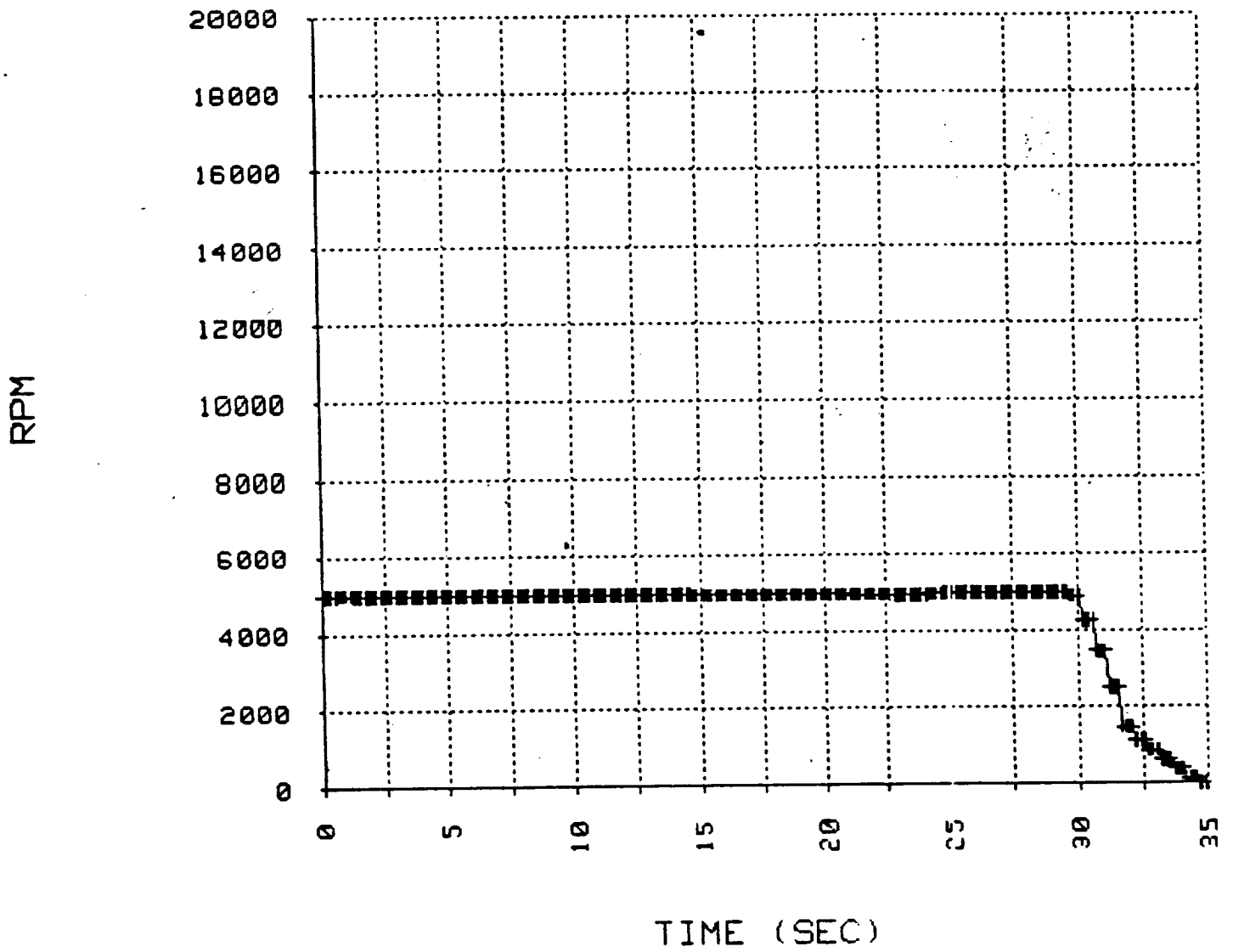
NORMAL LOAD (LBF)

FRT #211



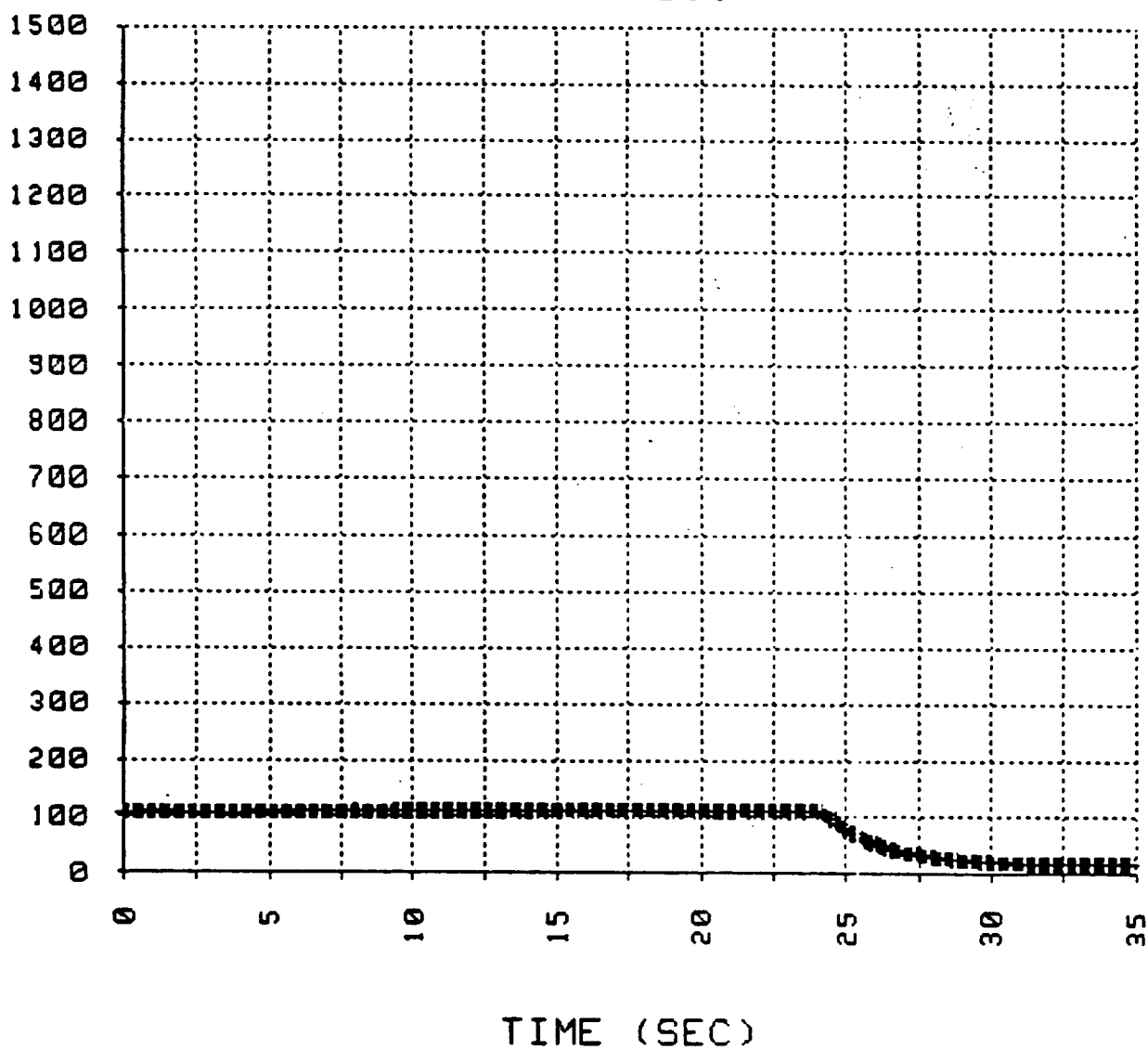
TIME (SEC)

FRT #211

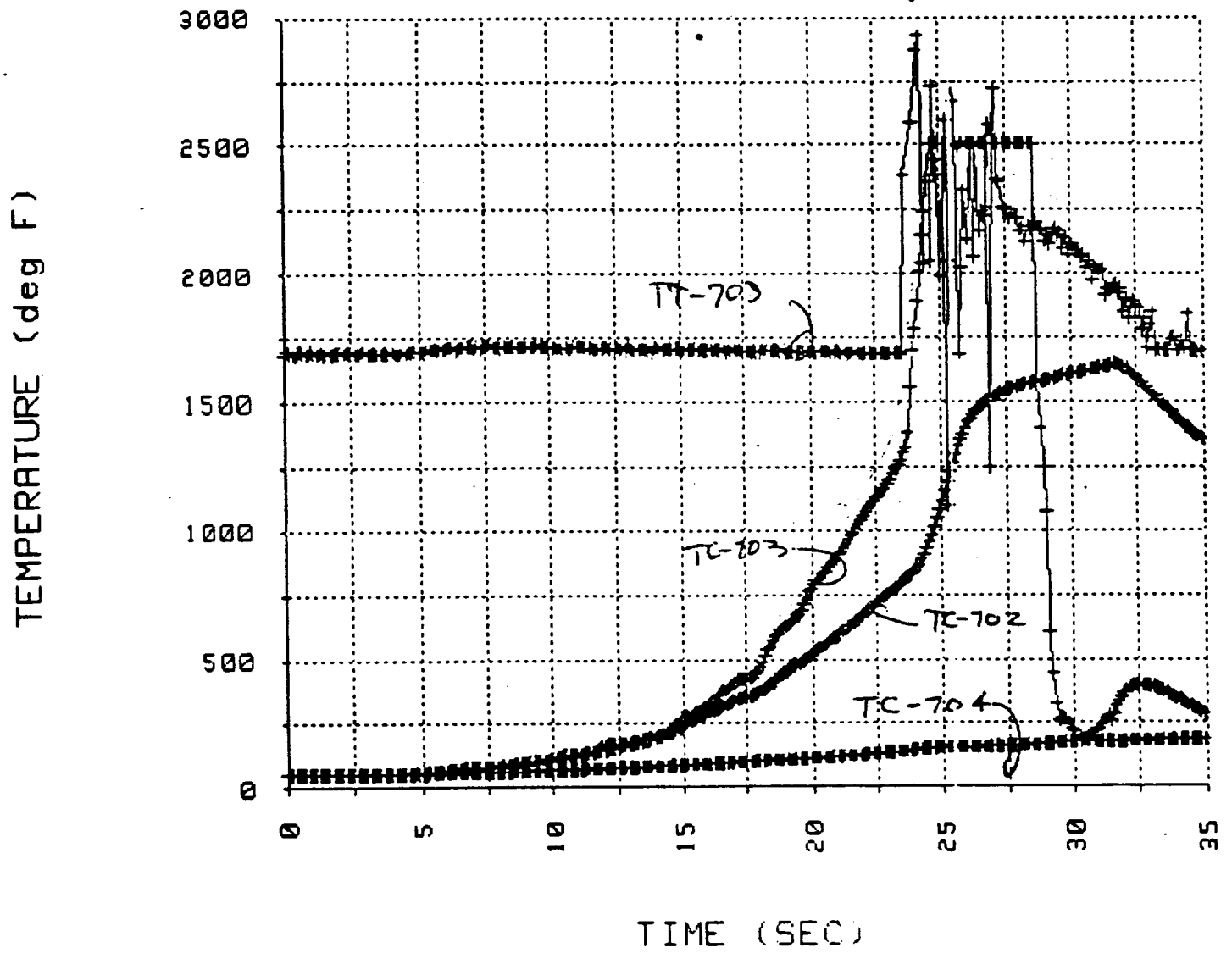


FRT #211

CHAMBER PRESSURE (PSIG)

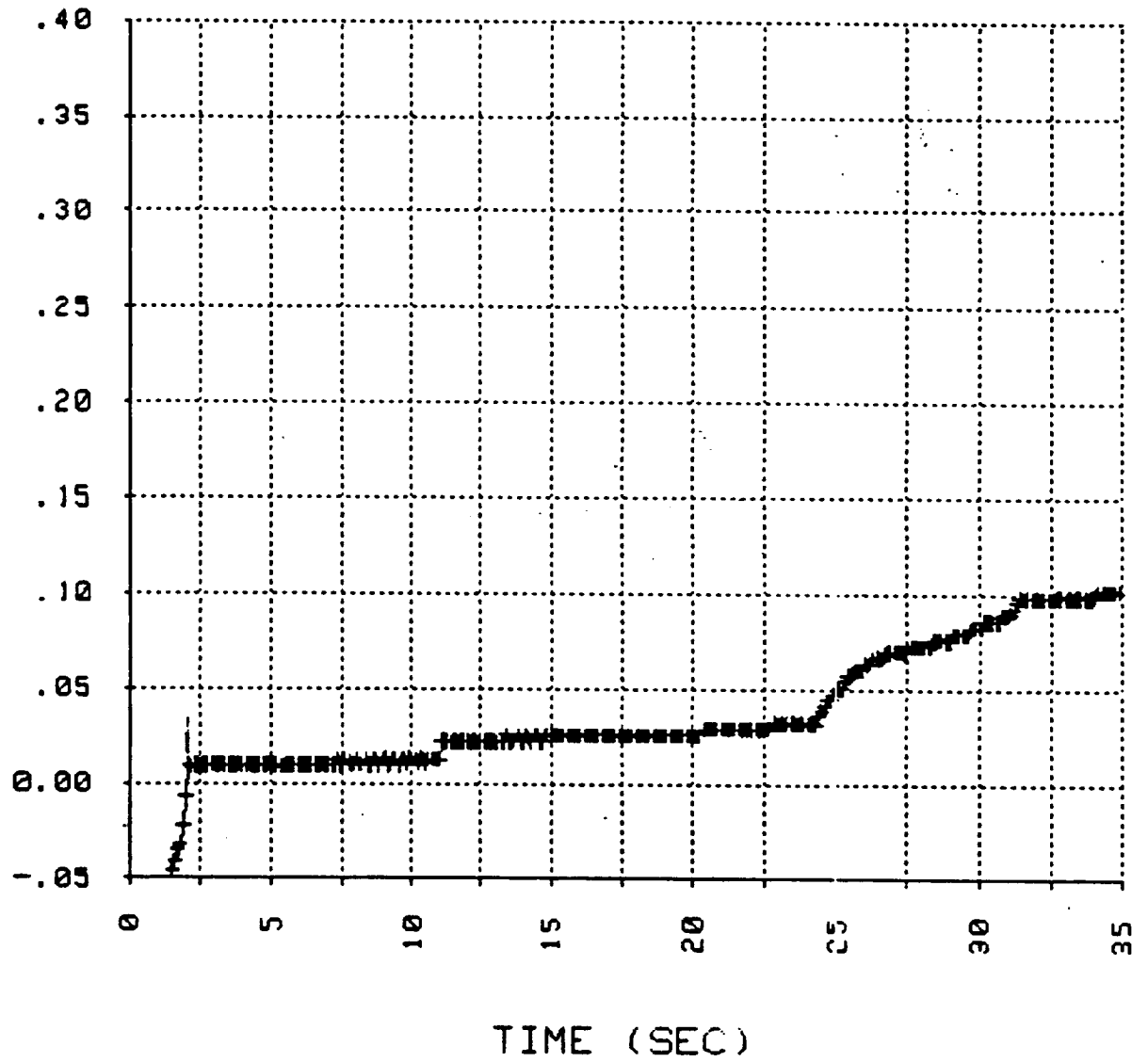


FRT #211 (100 PSIG)



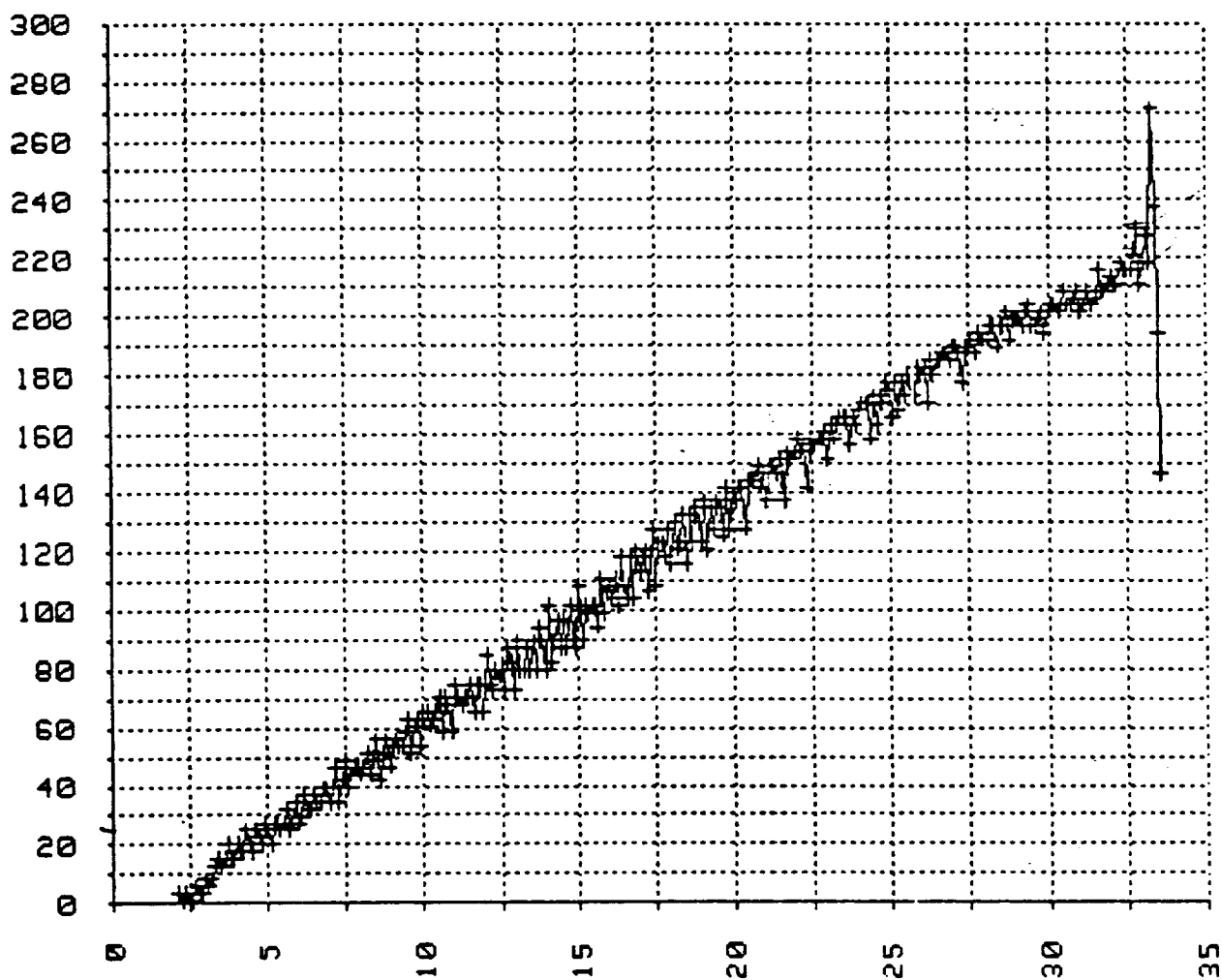
FRT #211

DISPLACEMENT (in)



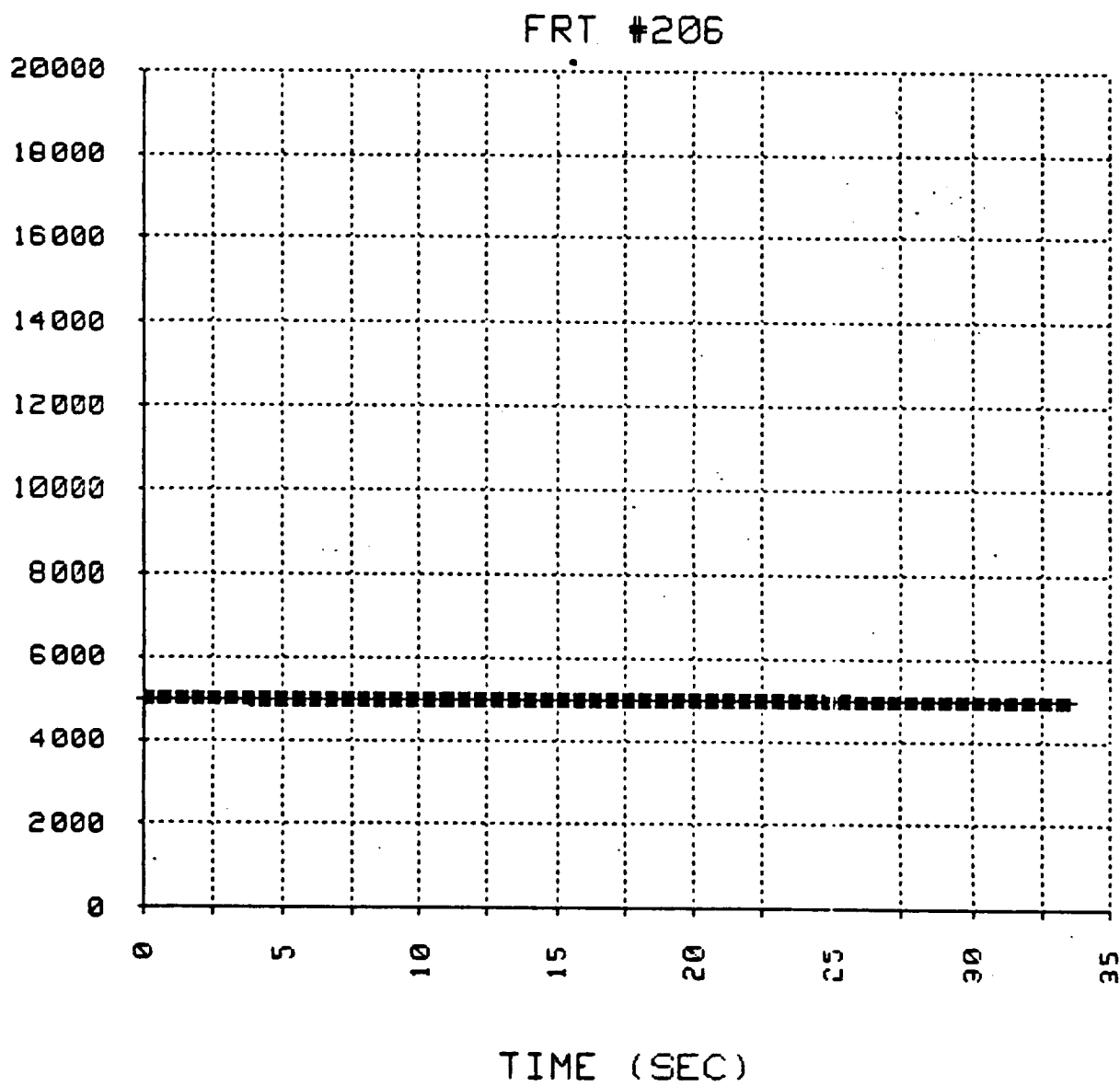
NORMAL LOAD (LBF)

FRT #206



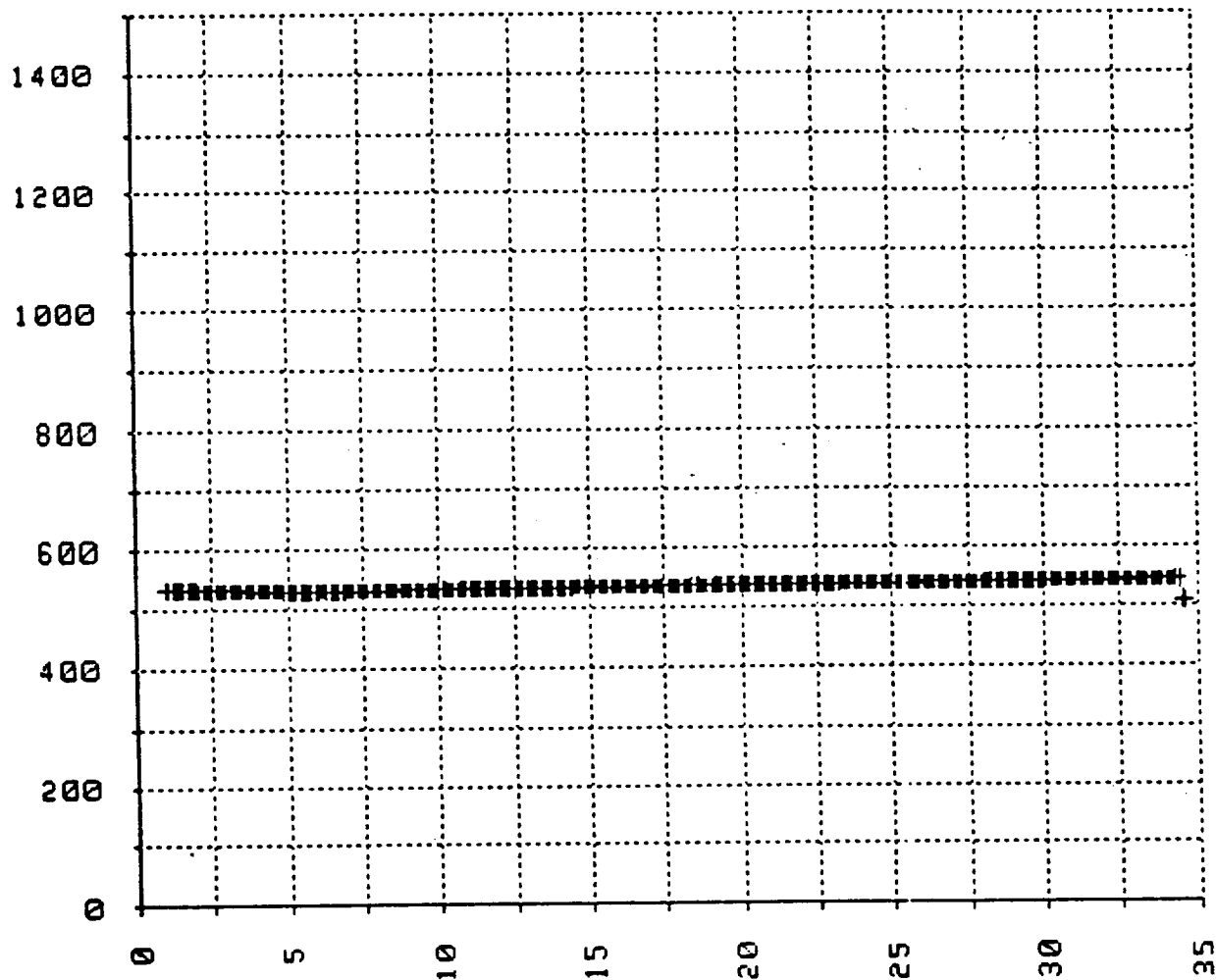
TIME (SEC)

RPM



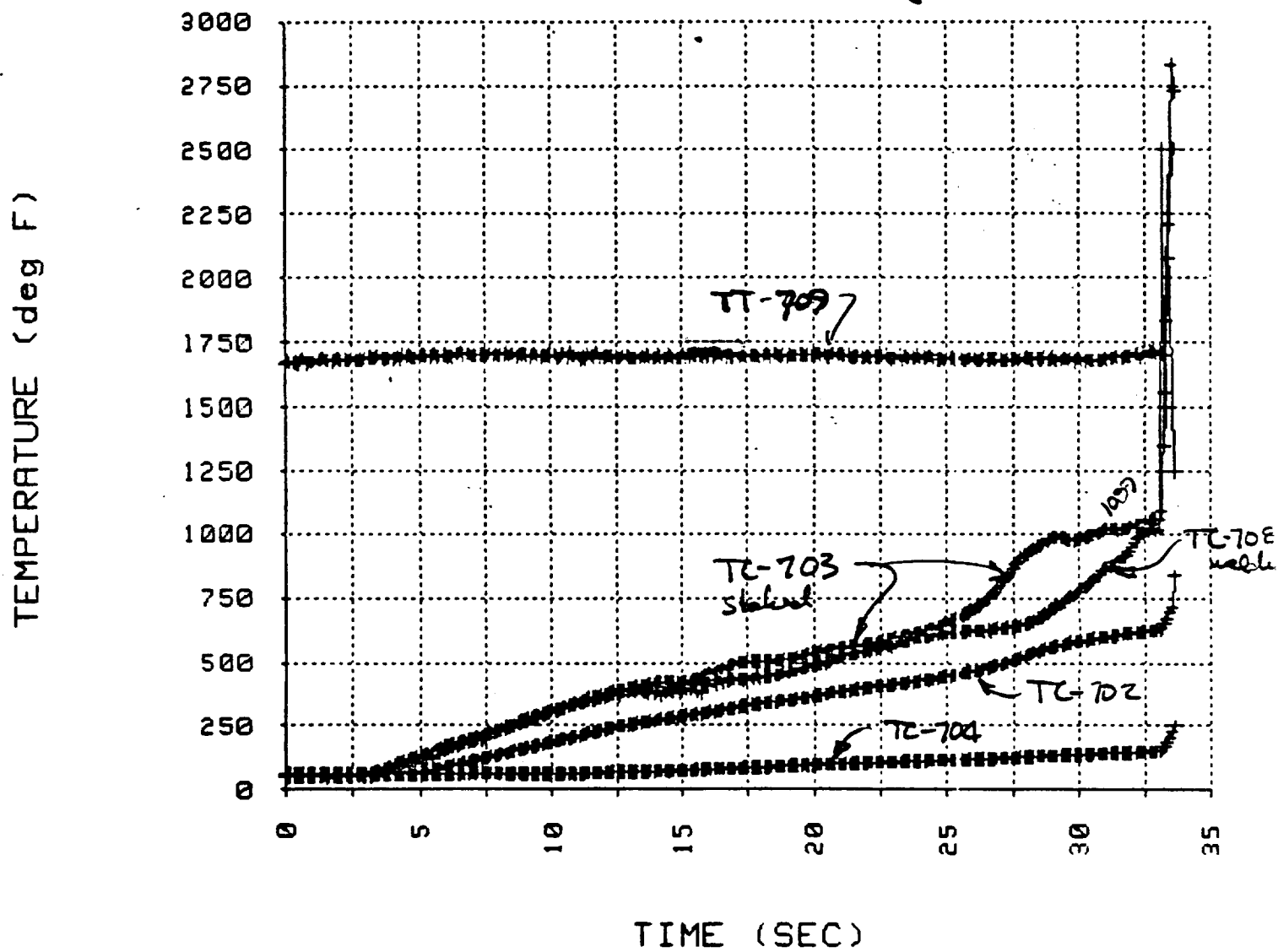
FRT #206

CHAMBER PRESSURE (PSIG)



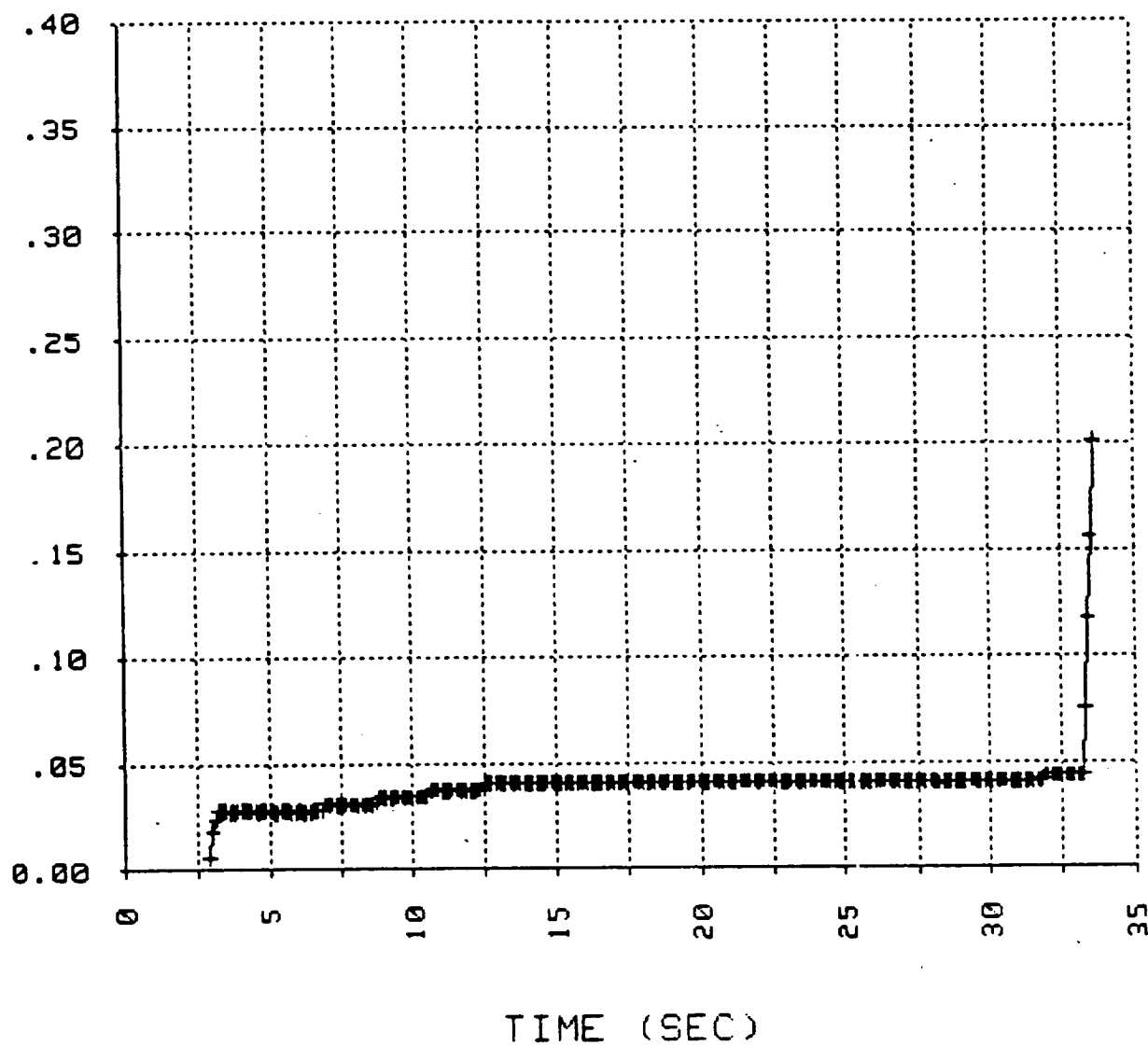
TIME (SEC)

FRT #206 (500 PSIG)

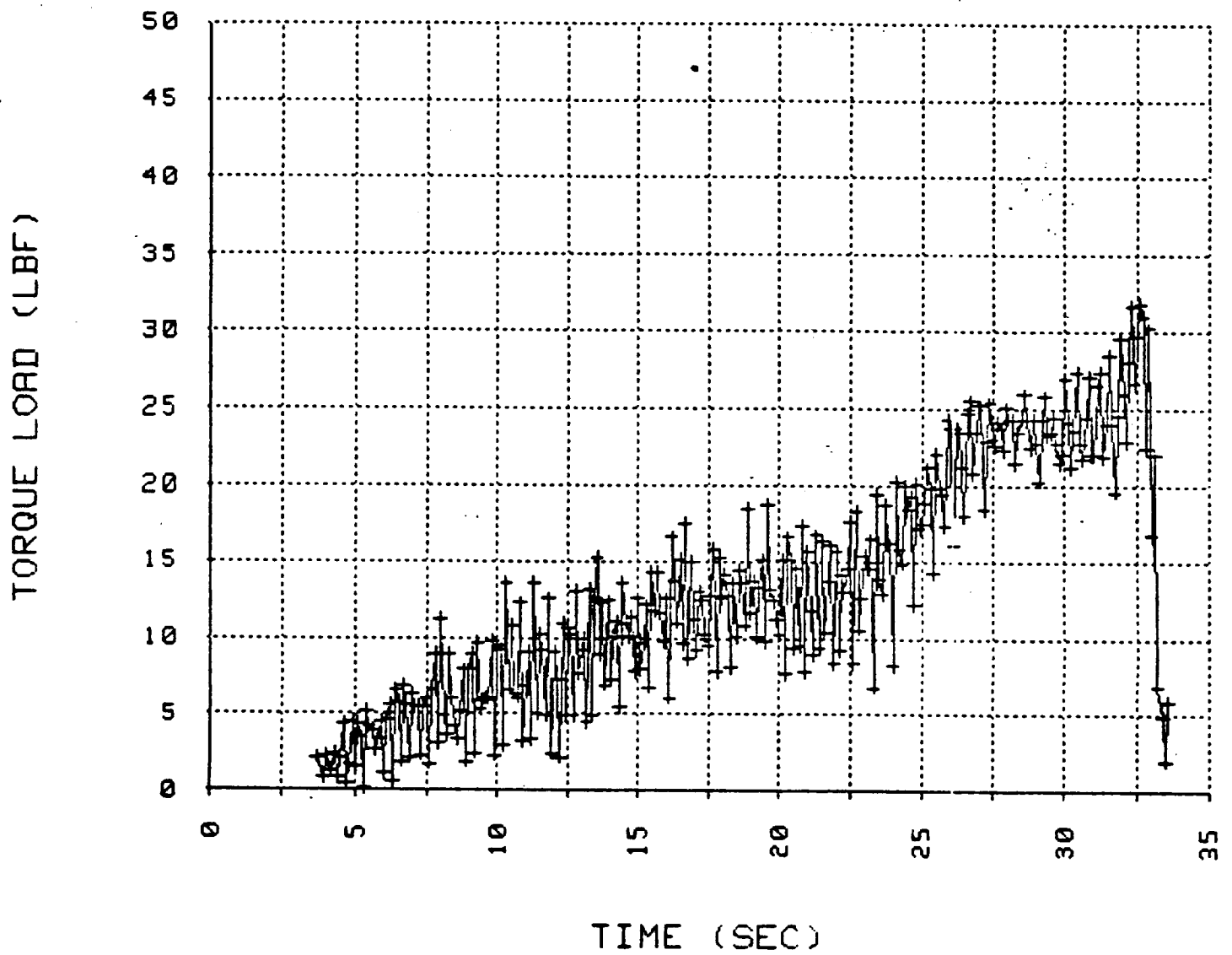


FRT #206

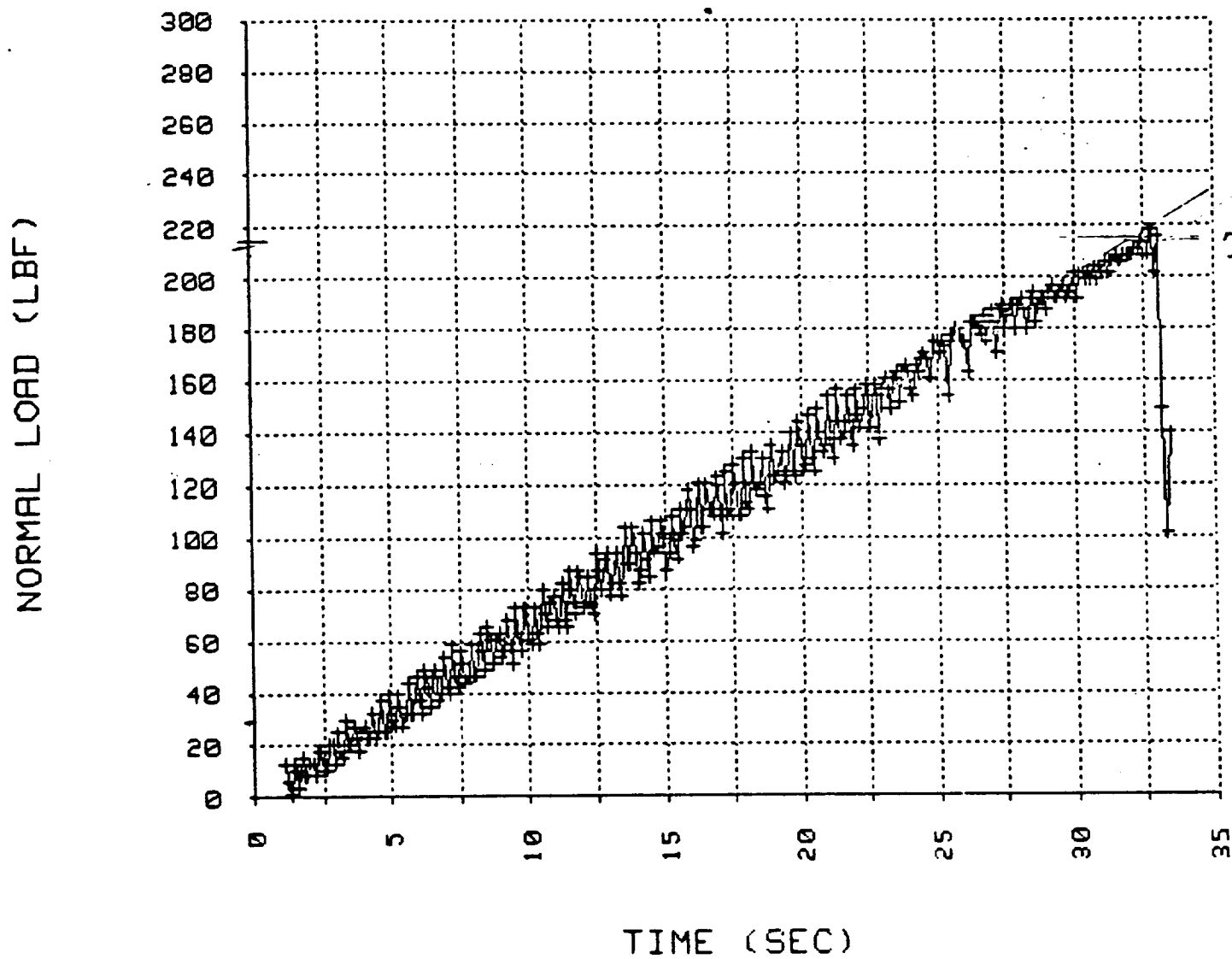
DISPLACEMENT (in)



FRT #206

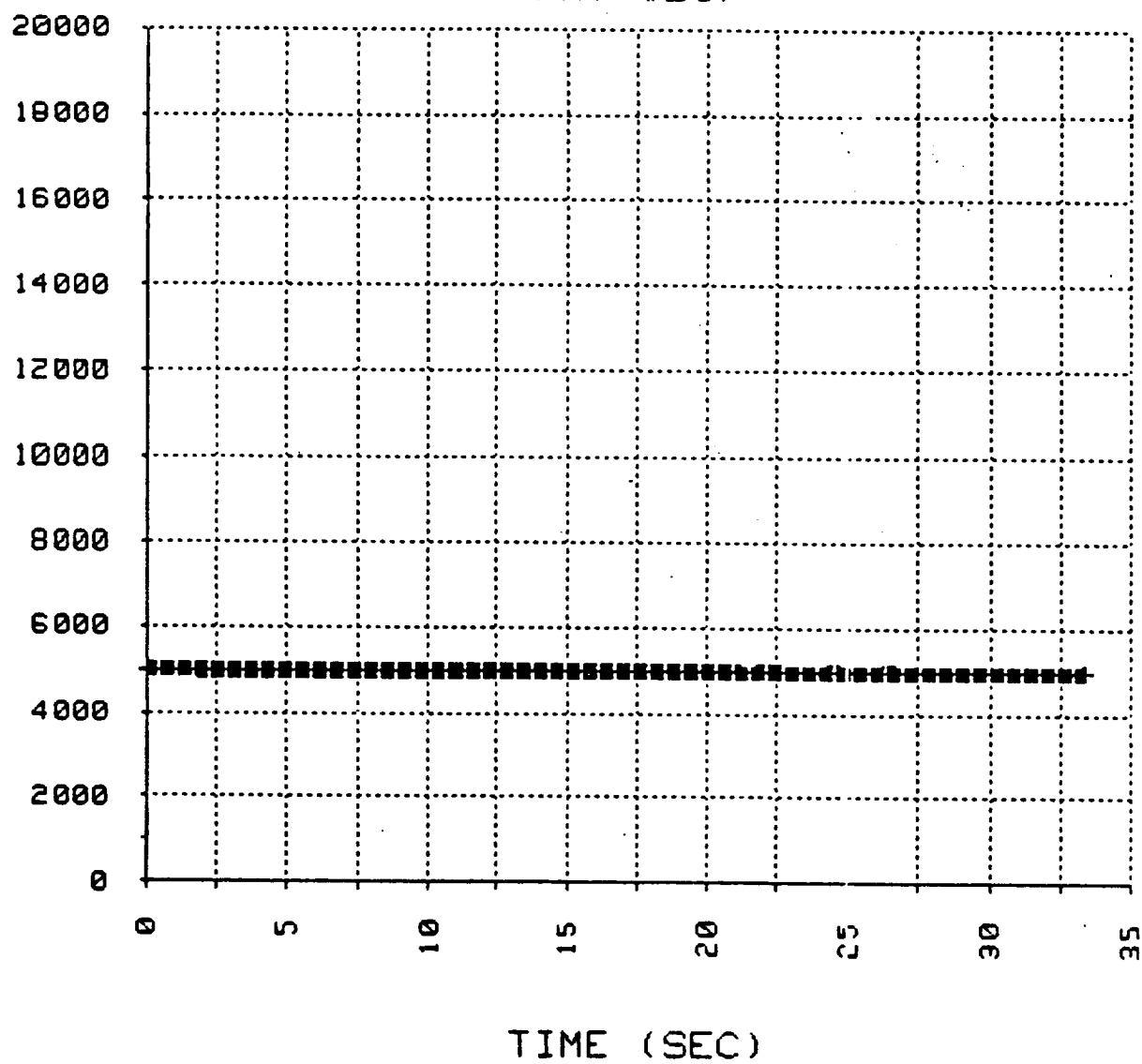


FRT #207



RPM

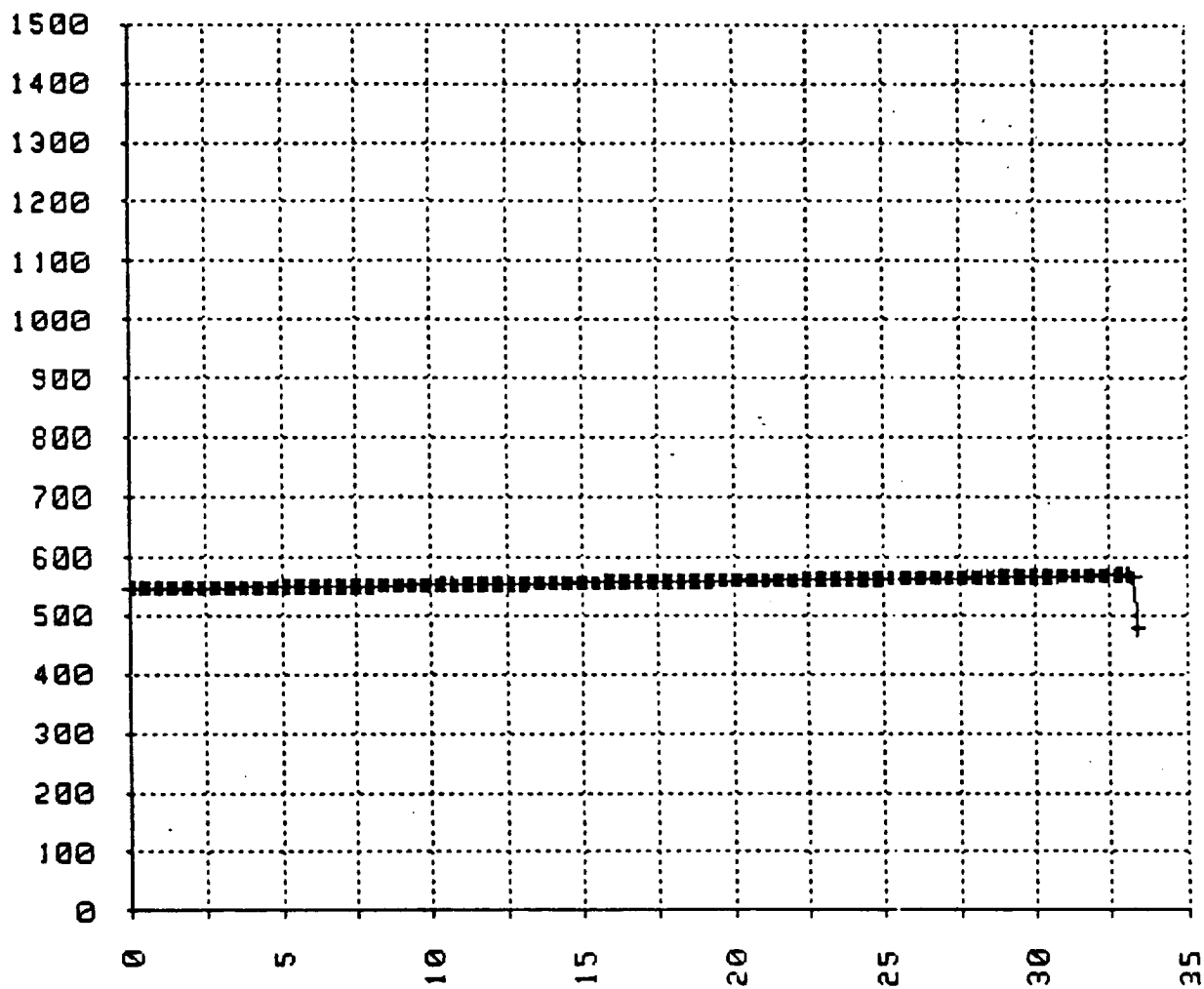
FRT #207



F-145

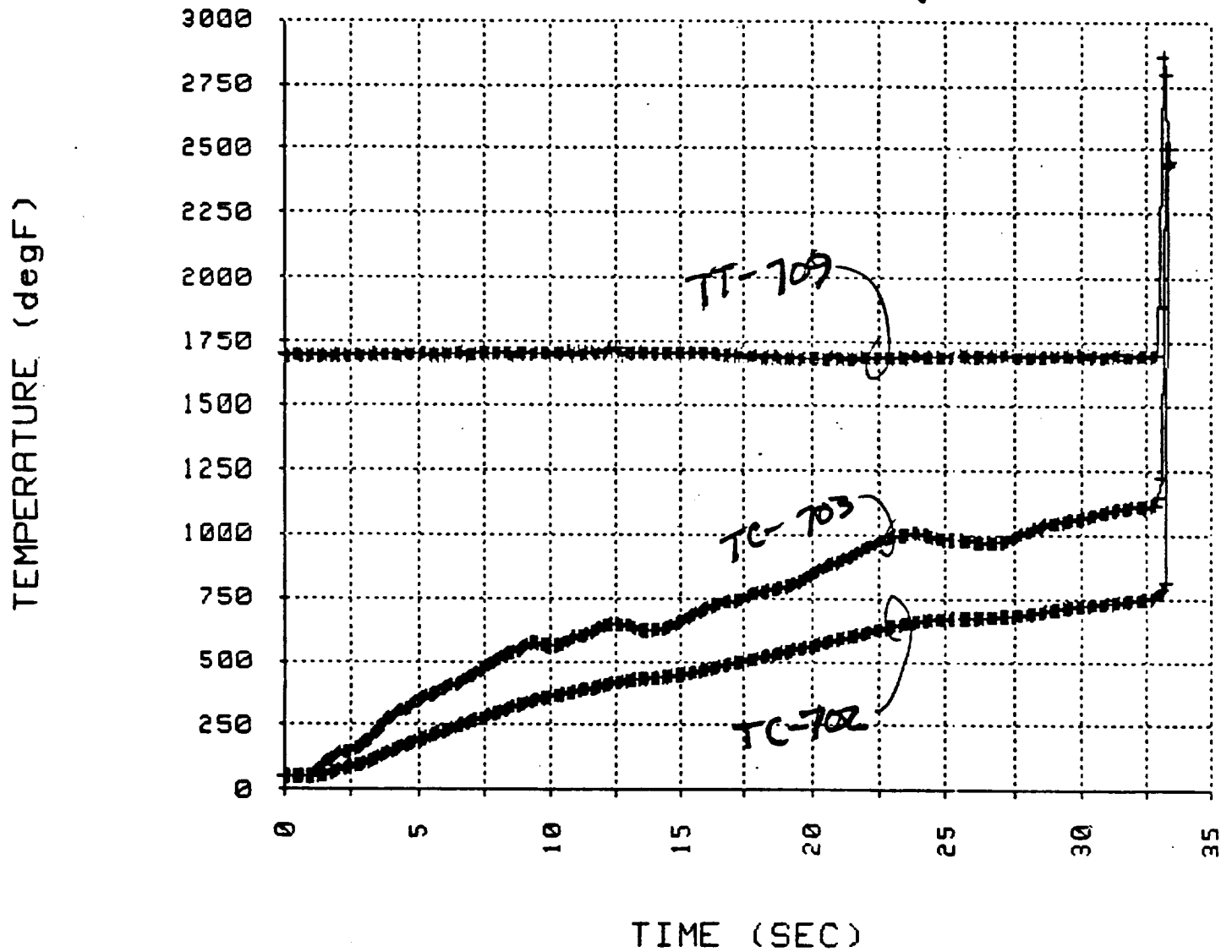
FRT #207

CHAMBER PRESSURE (PSIG)

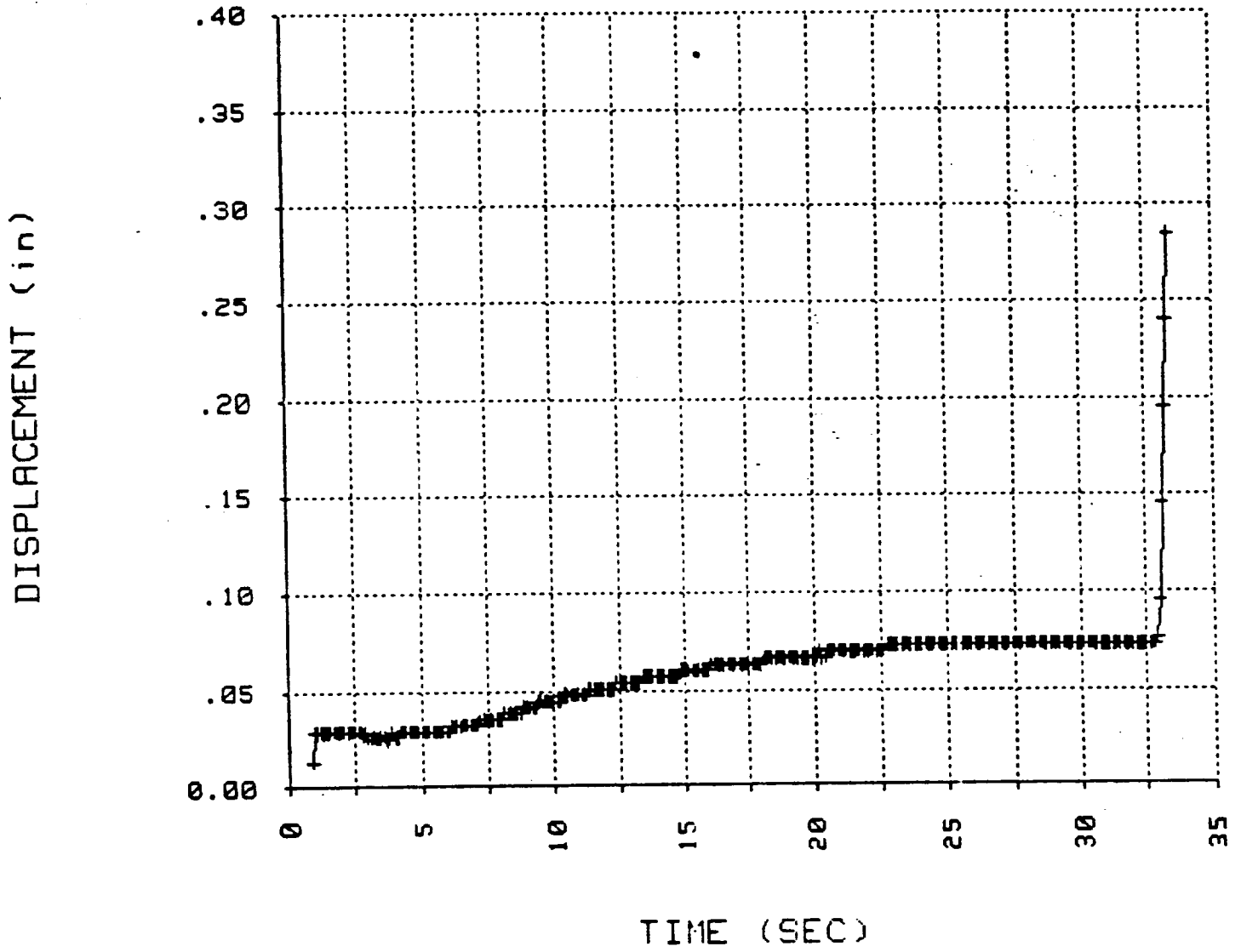


TIME (SEC)

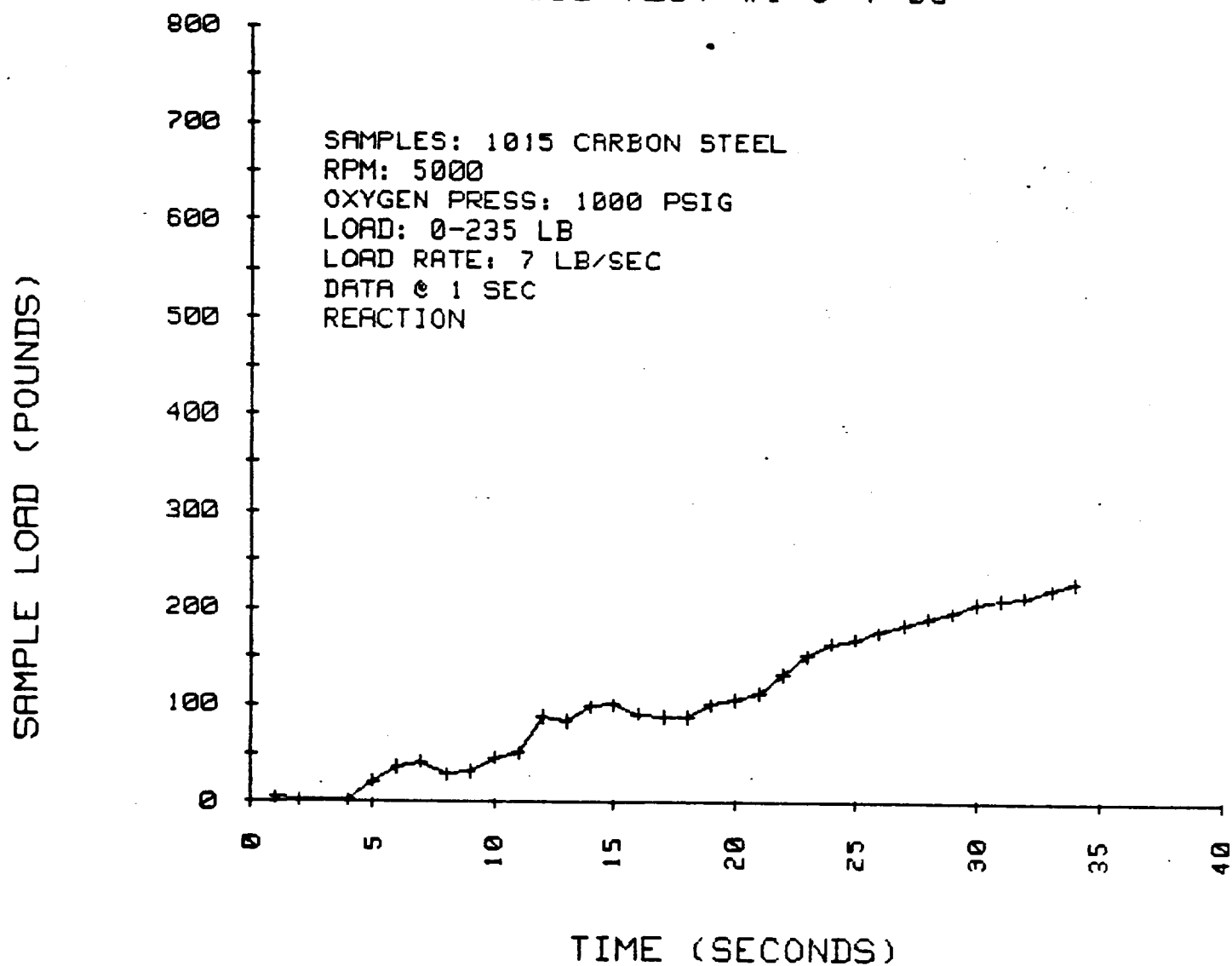
FRT #207 (500 PSIG)



FRT #207



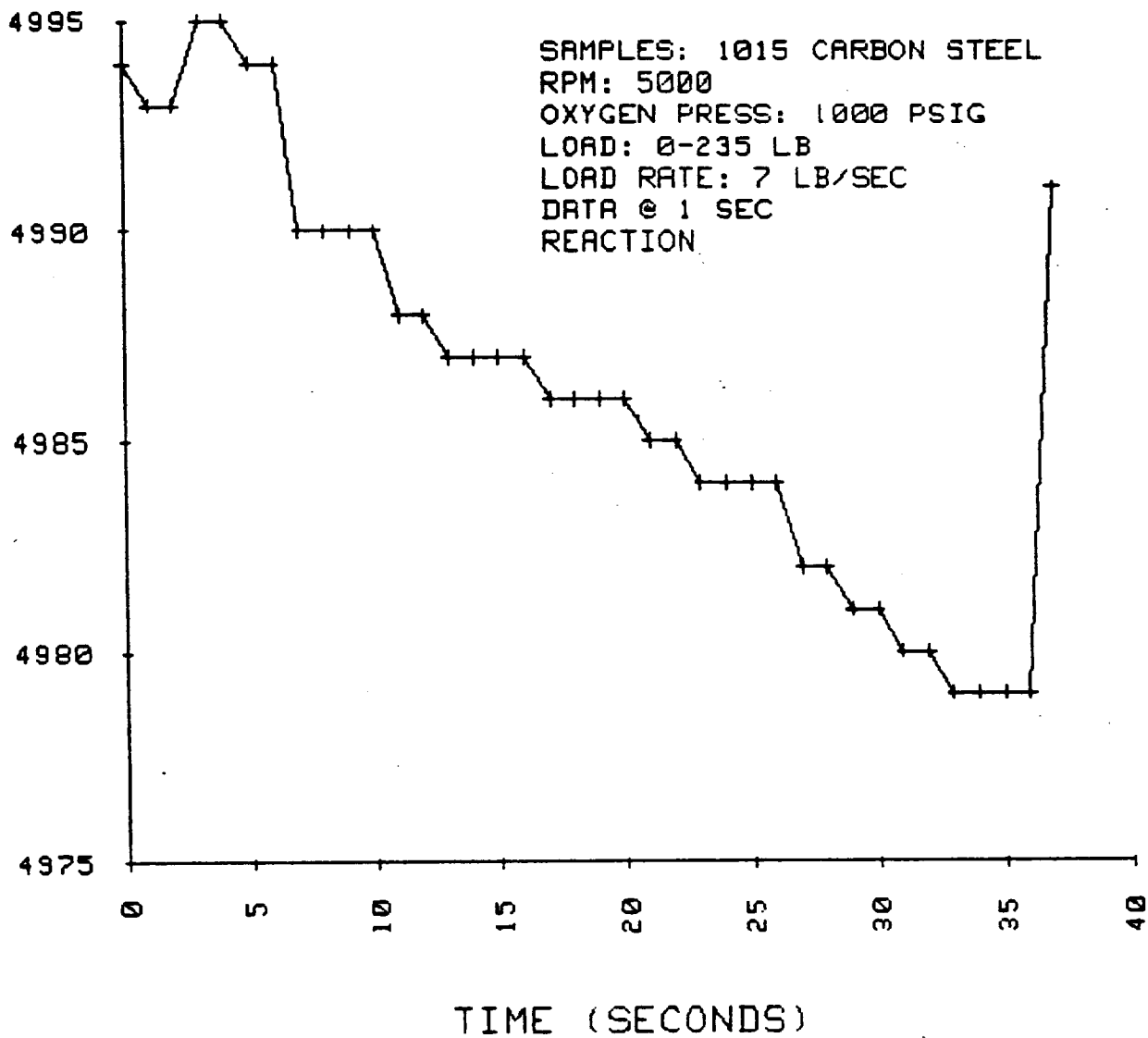
FRT #92 TEST #1 3/4/83



FRT #92 TEST #1 3/4/83

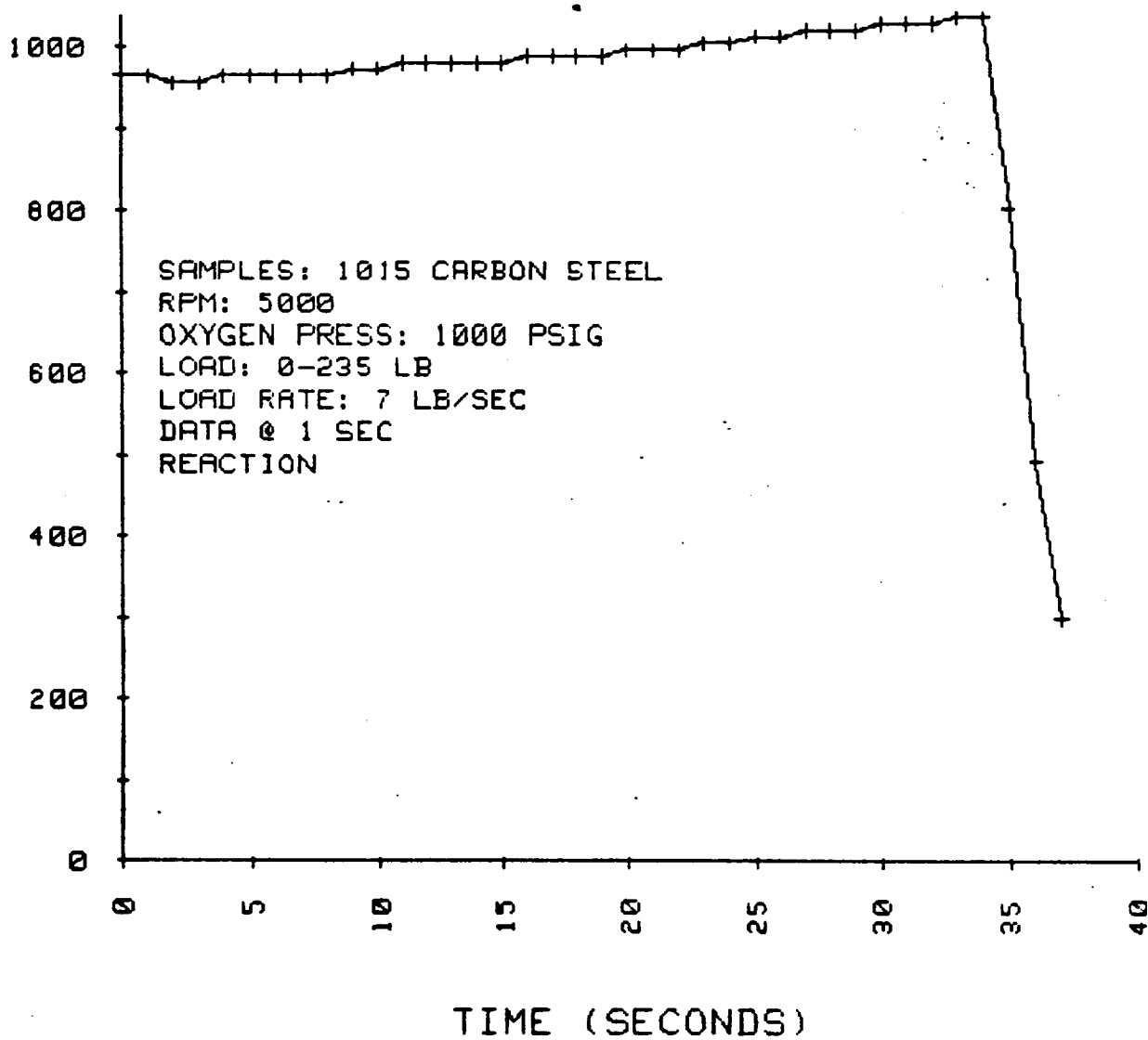
SAMPLES: 1015 CARBON STEEL
RPM: 5000
OXYGEN PRESS: 1000 PSIG
LOAD: 0-235 LB
LOAD RATE: 7 LB/SEC
DATA @ 1 SEC
REACTION

RPM (REVOLUTIONS PER MINUTE)

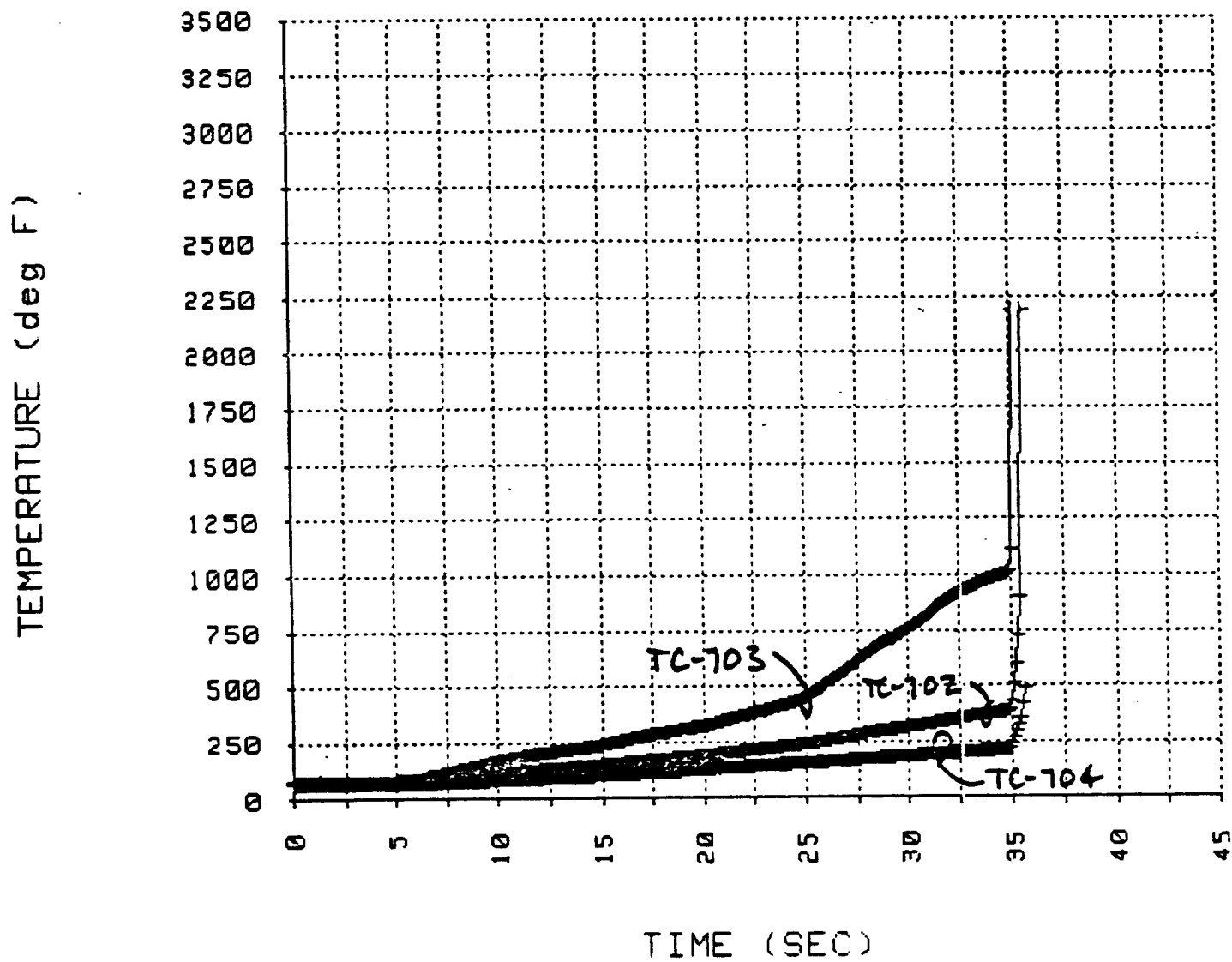


CHAMBER PRESSURE (PSIG)

FRT #92 TEST #1 3/4/83

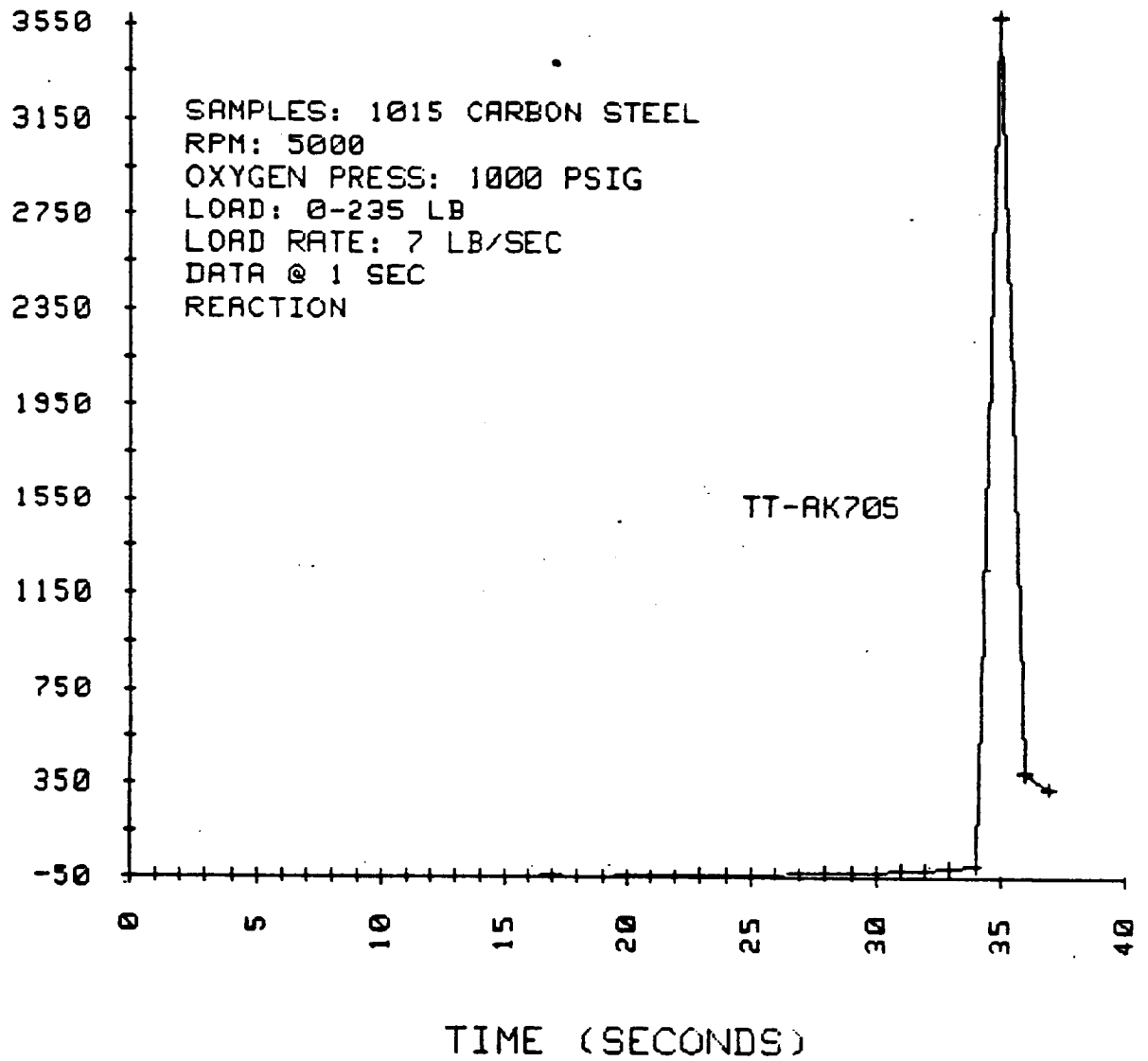


FRT #92 (1000 PSIG)



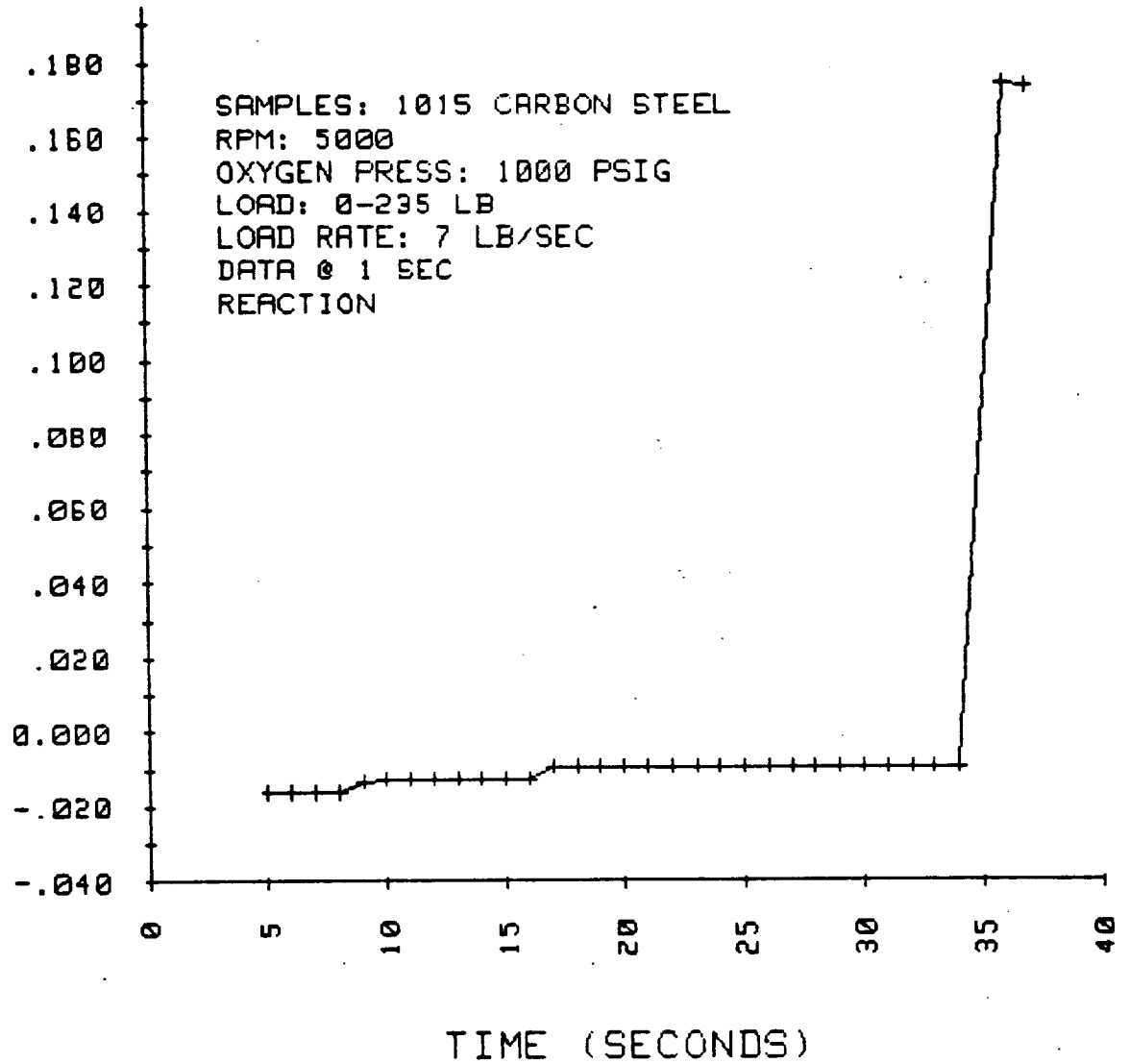
THERMOPILE OUTPUT (1/100MV)

FRT #92 TEST #1 3/4/83



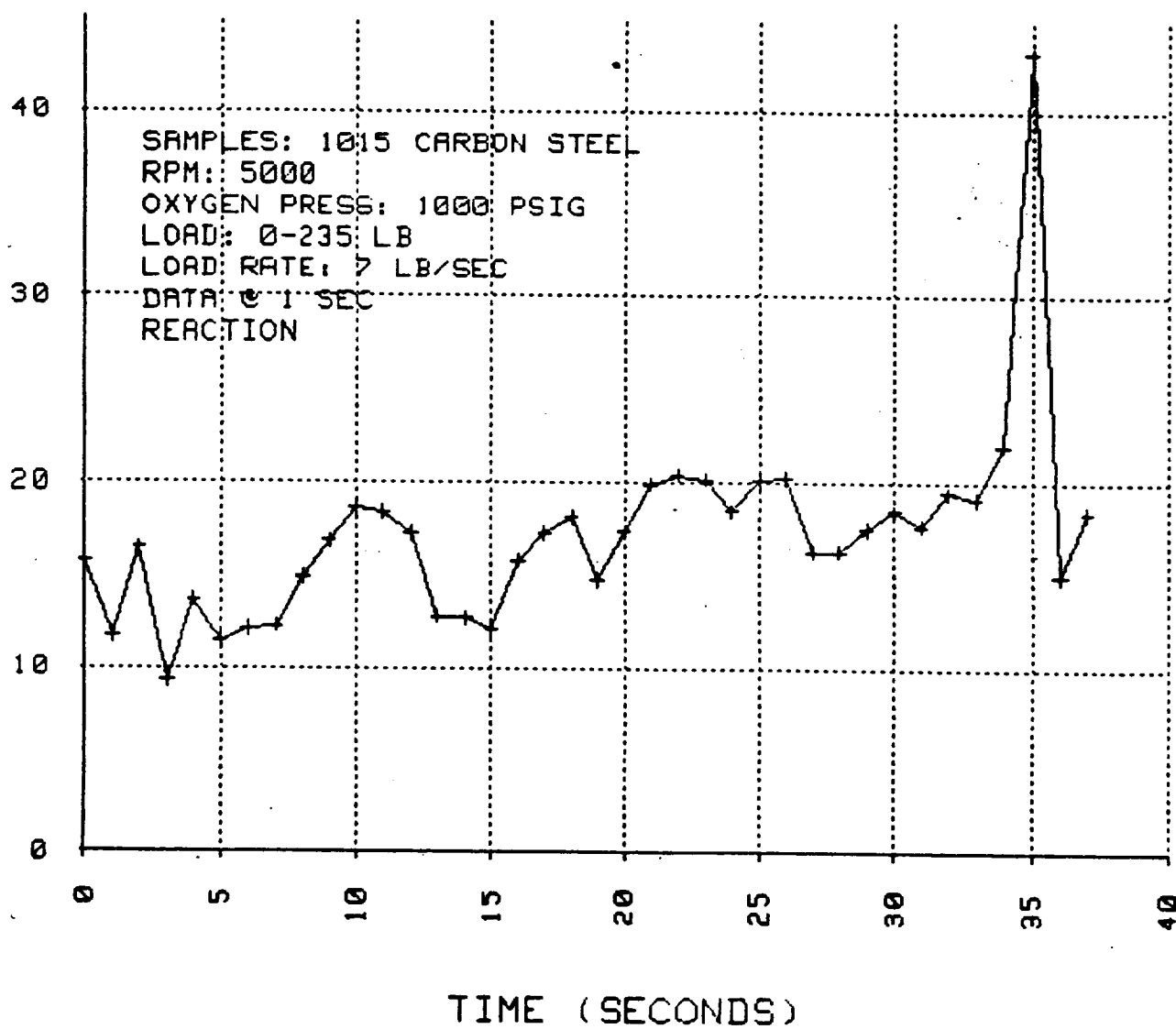
FRT #92 TEST #1 3/4/83

SAMPLE DISPLACEMENT (INCHES)

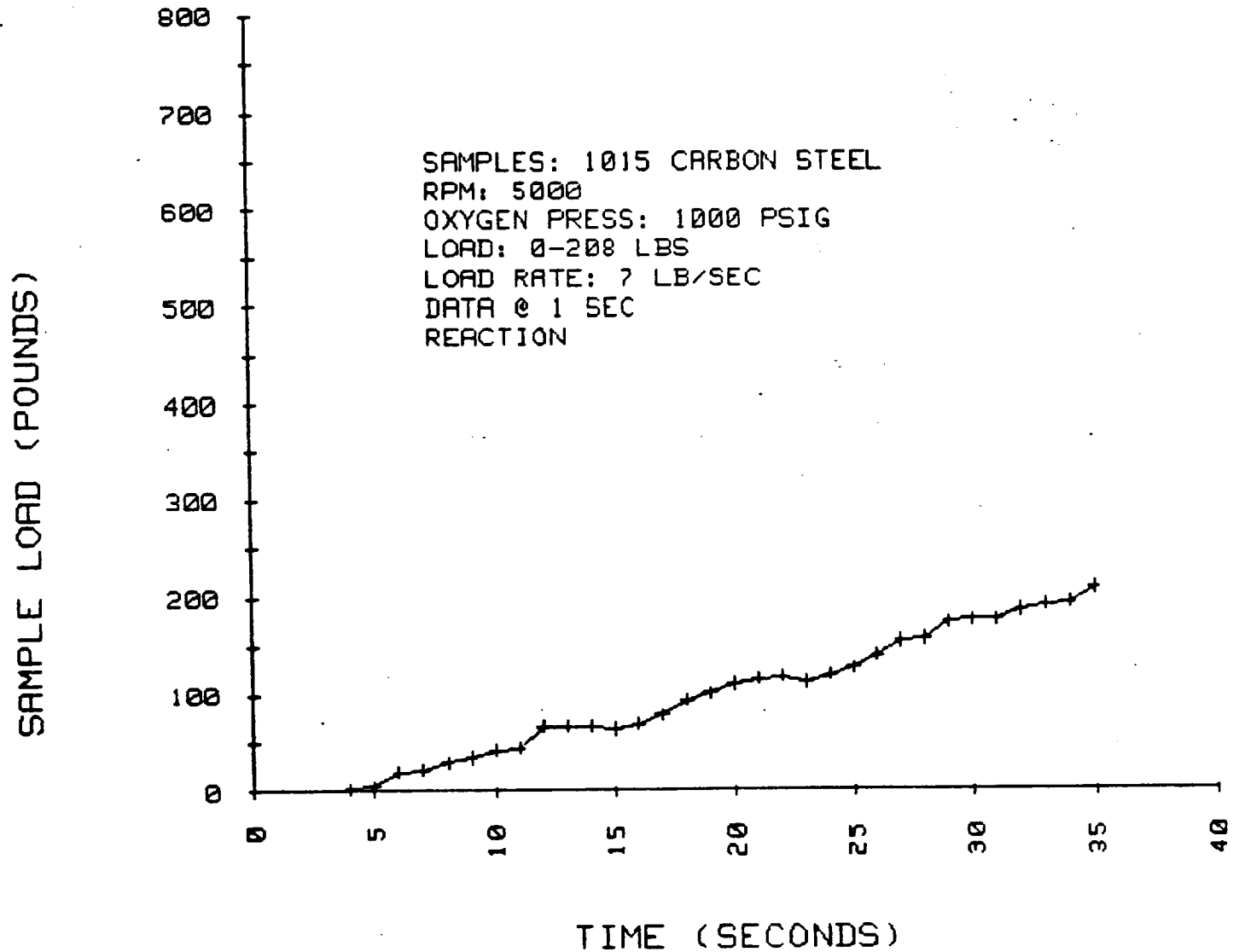


FRT #92 TEST #1 3/4/83

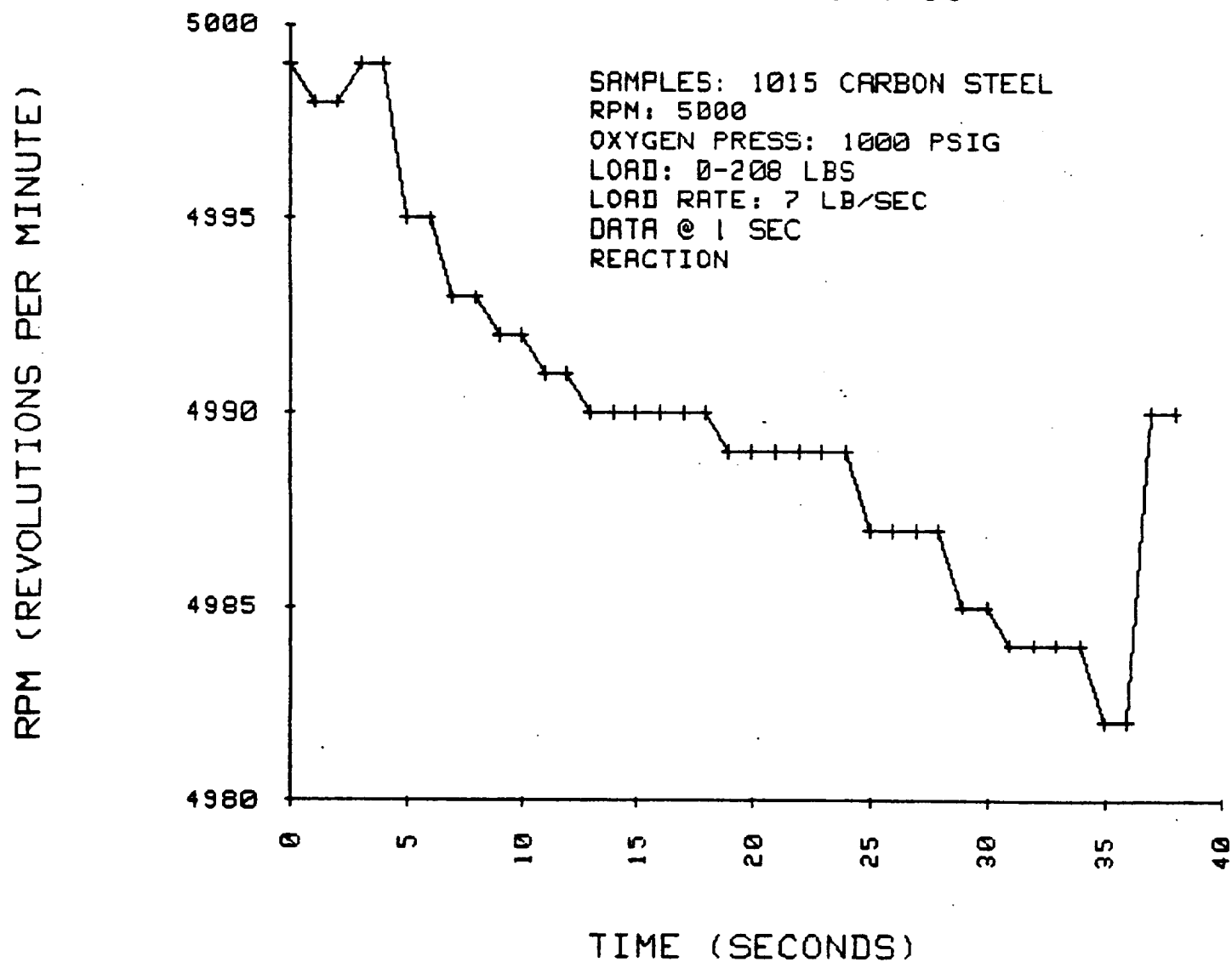
CHAMBER TORQUE LOAD (POUNDS)



FRT #93 TEST. #2 3/4/83

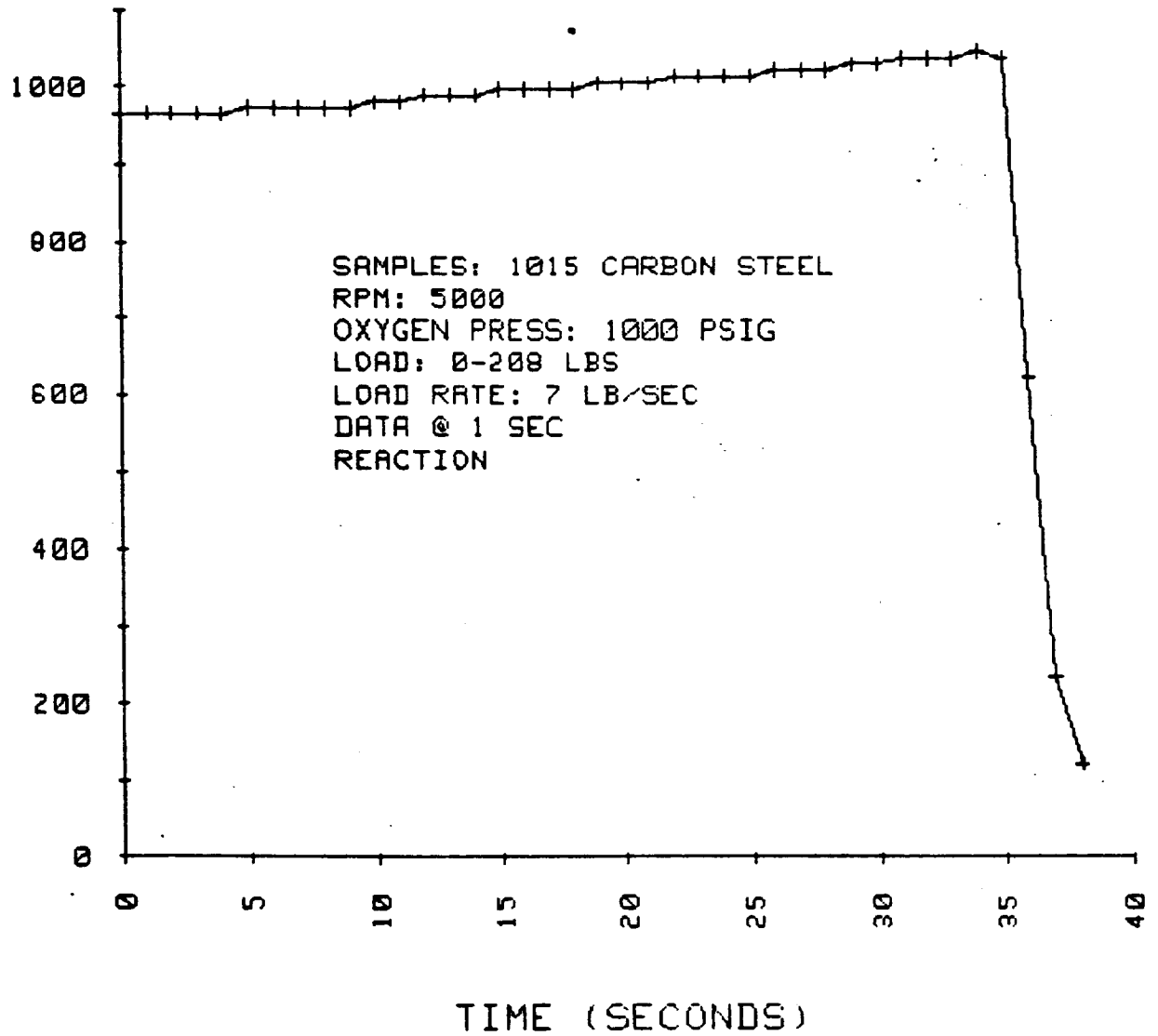


FRT #93 TEST #2 3/4/83



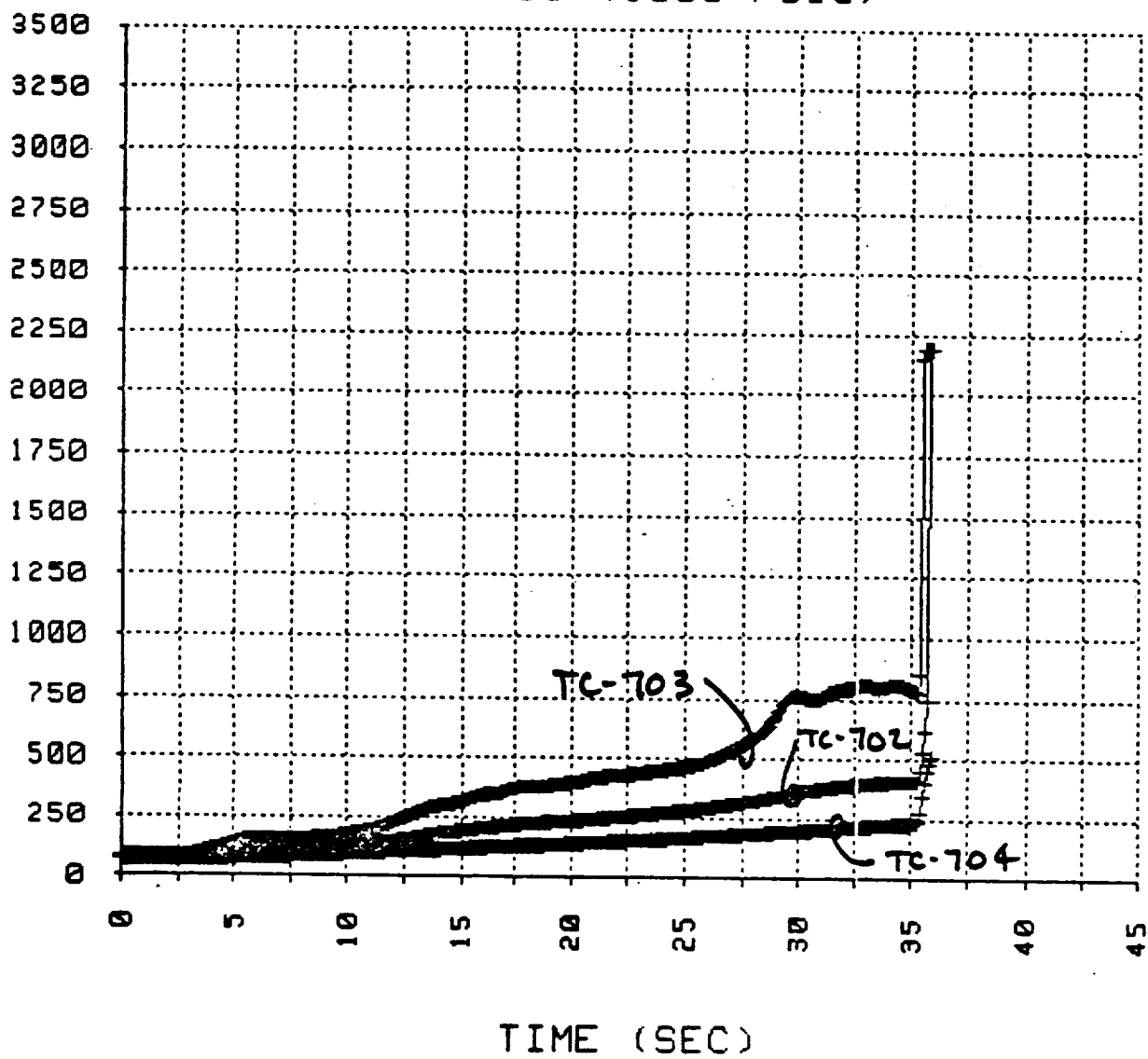
FRT #93 TEST #2 3/4/83

CHAMBER PRESSURE (PSIG)



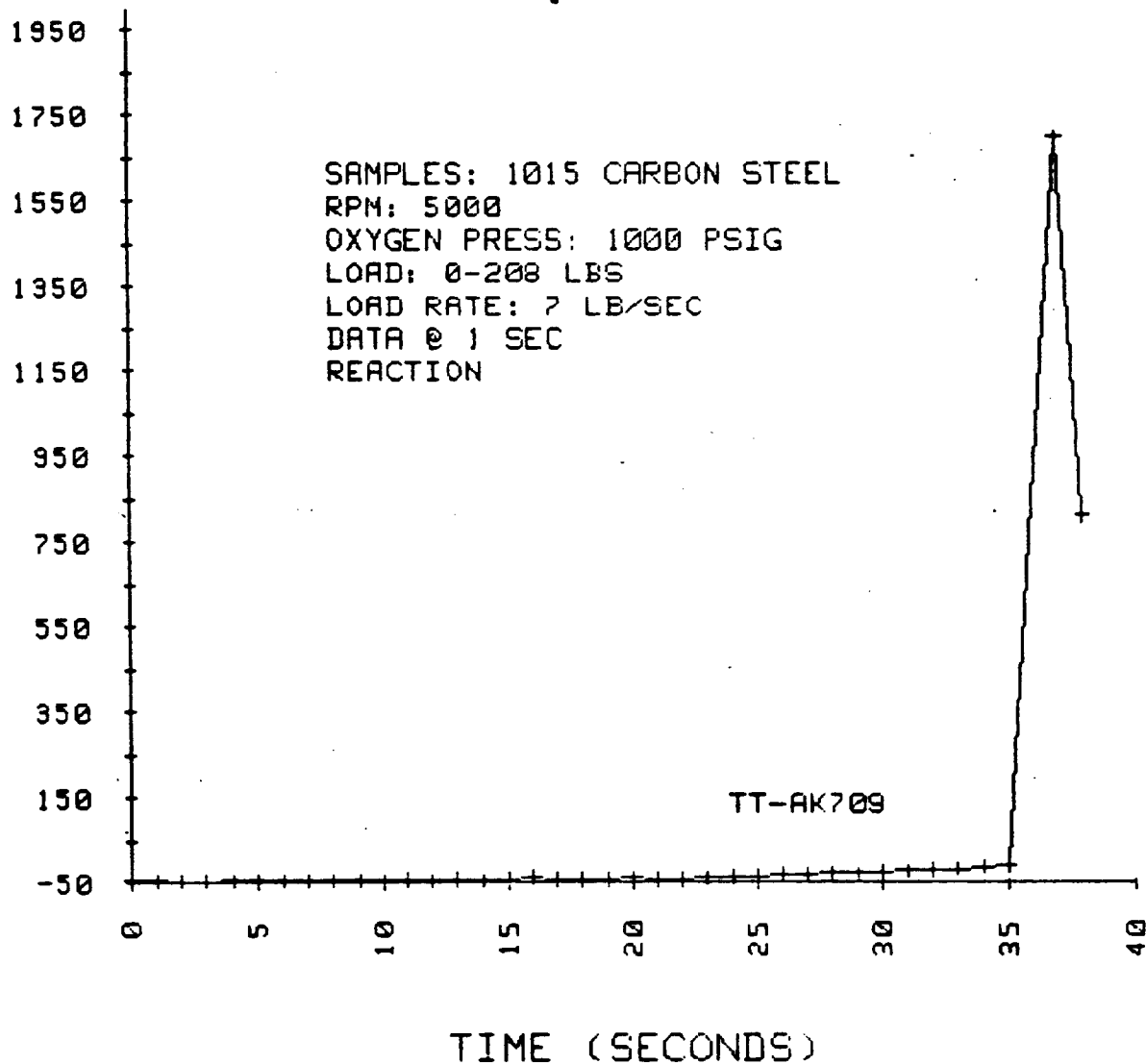
TEMPERATURE (deg F)

FRT #93 (1000 PSIG)



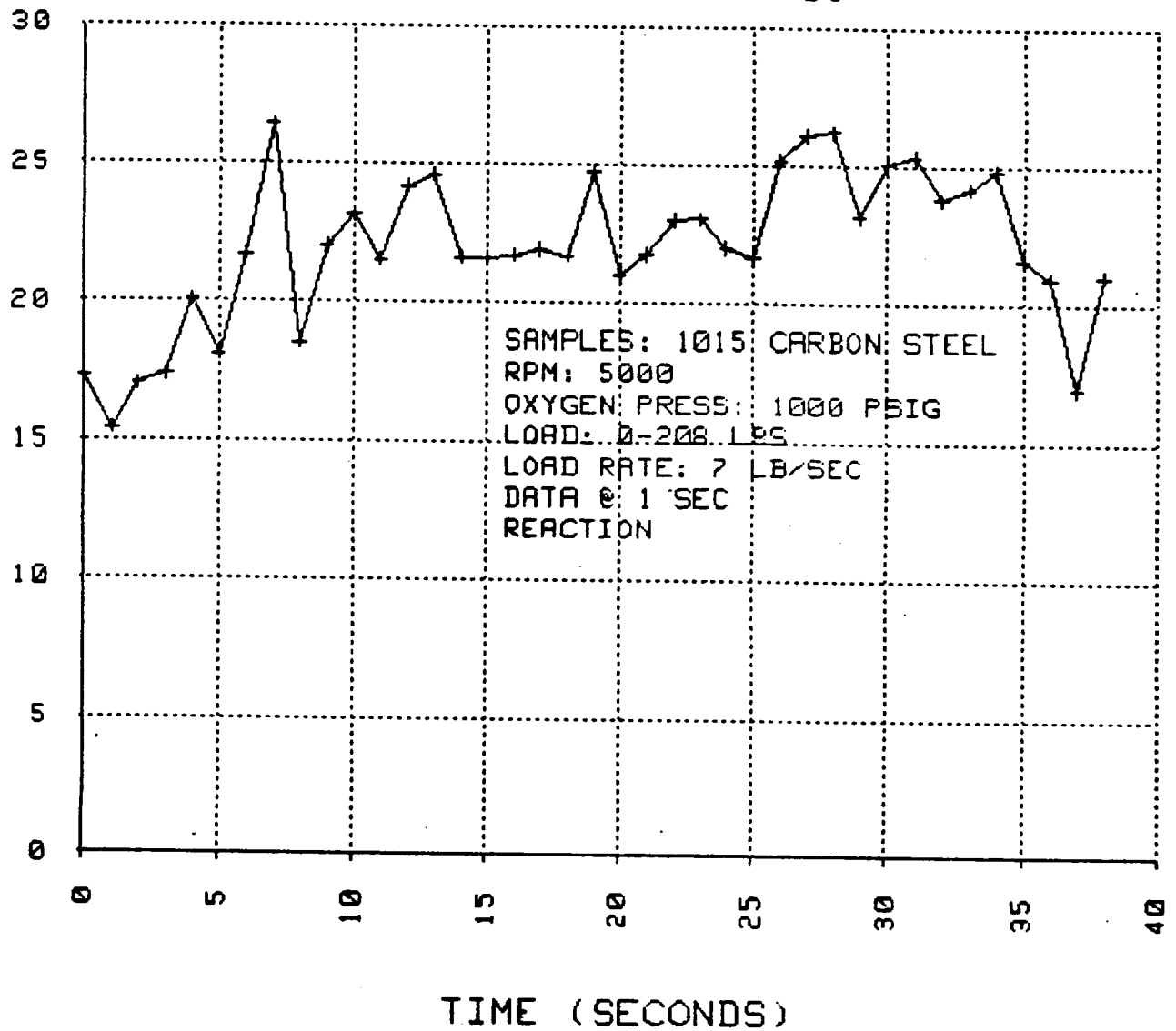
FRT #93 TEST #2 3/4/83

THERMOPILE OUTPUT (1/100MV)

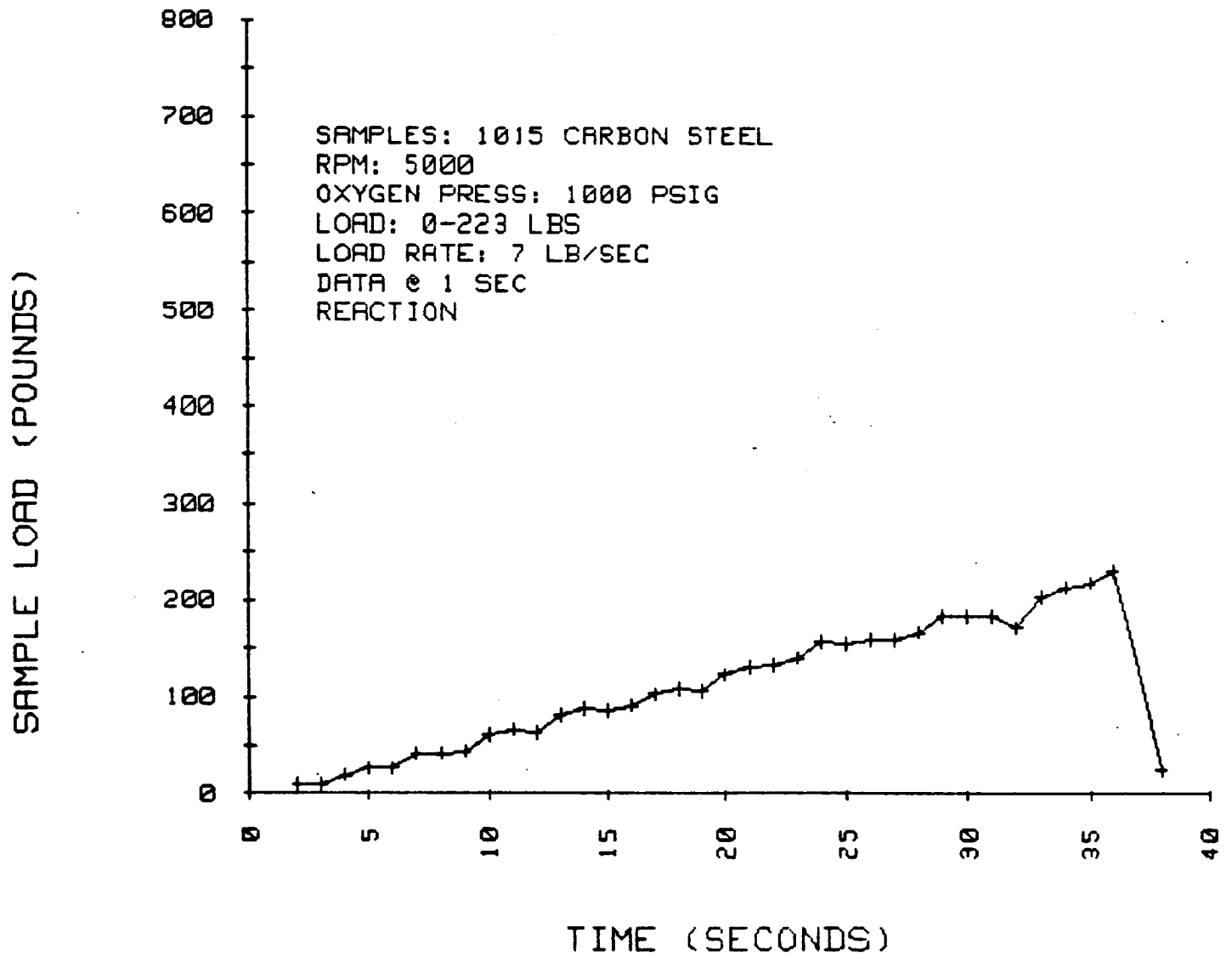


FRT #93 TEST #2 3/4/83

CHAMBER TORQUE LOAD (POUNDS)

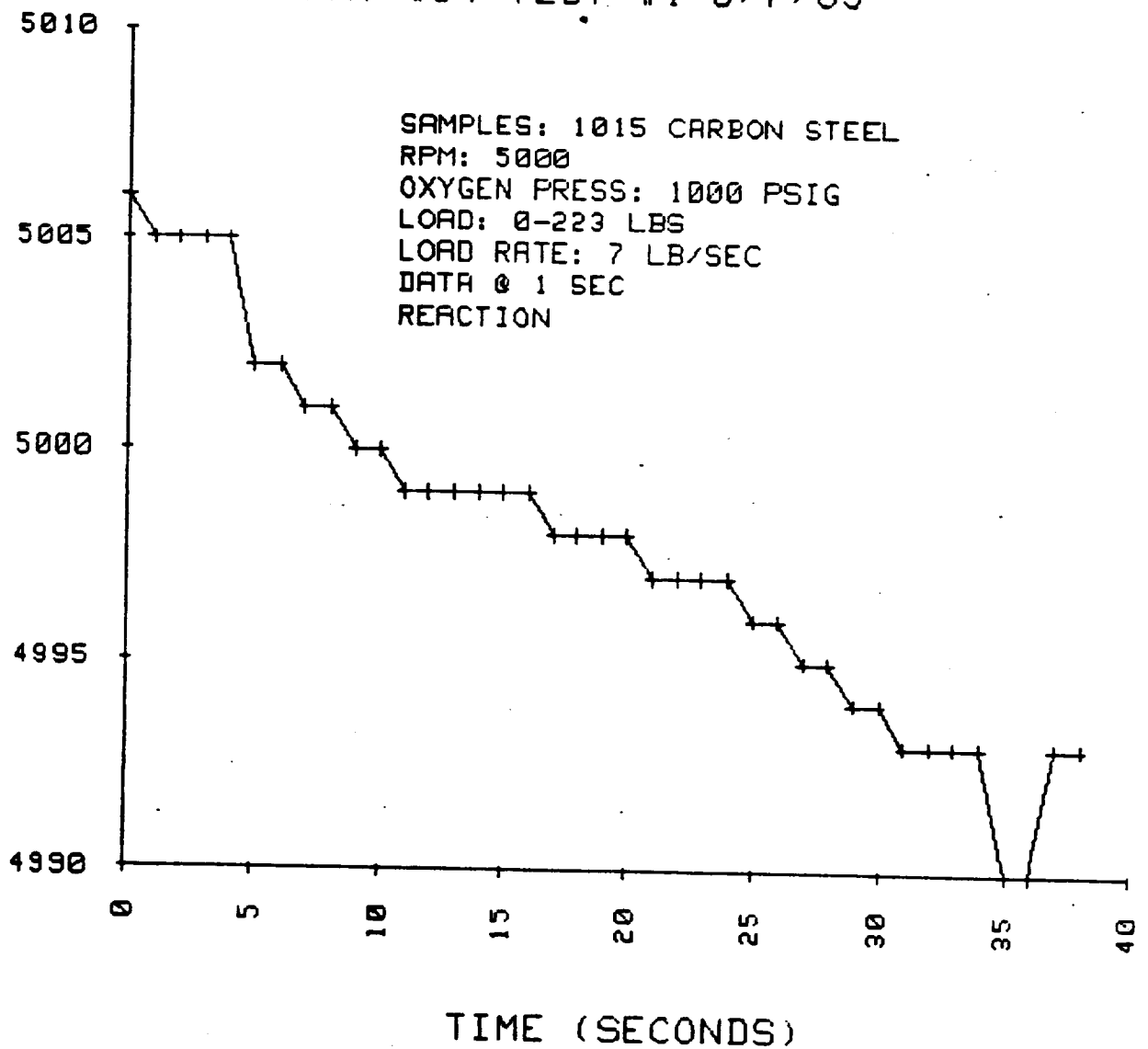


FRT #94 TEST #1 3/7/83



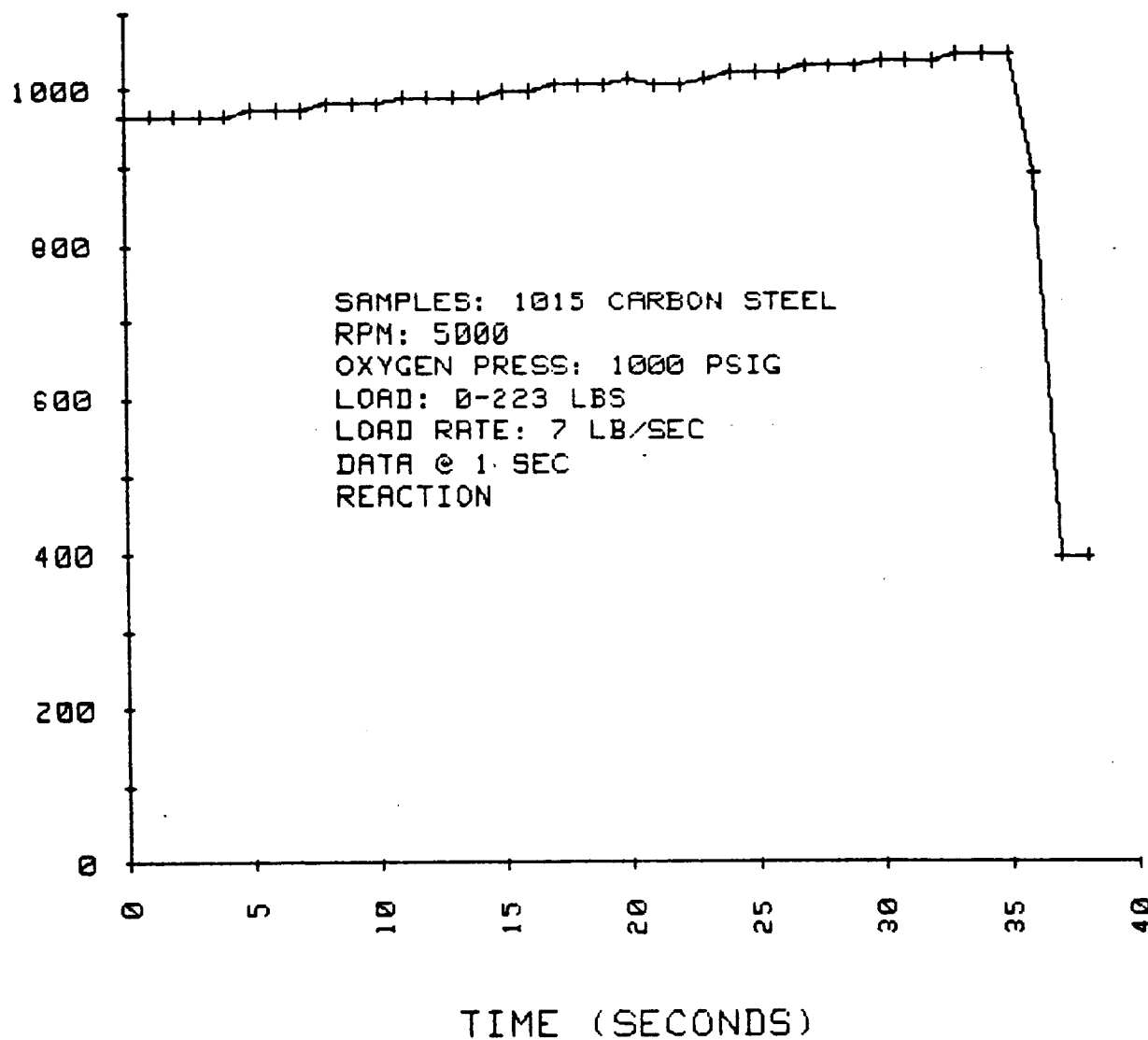
FRT #94 TEST #1 3/7/83

RPM (REVOLUTIONS PER MINUTE)

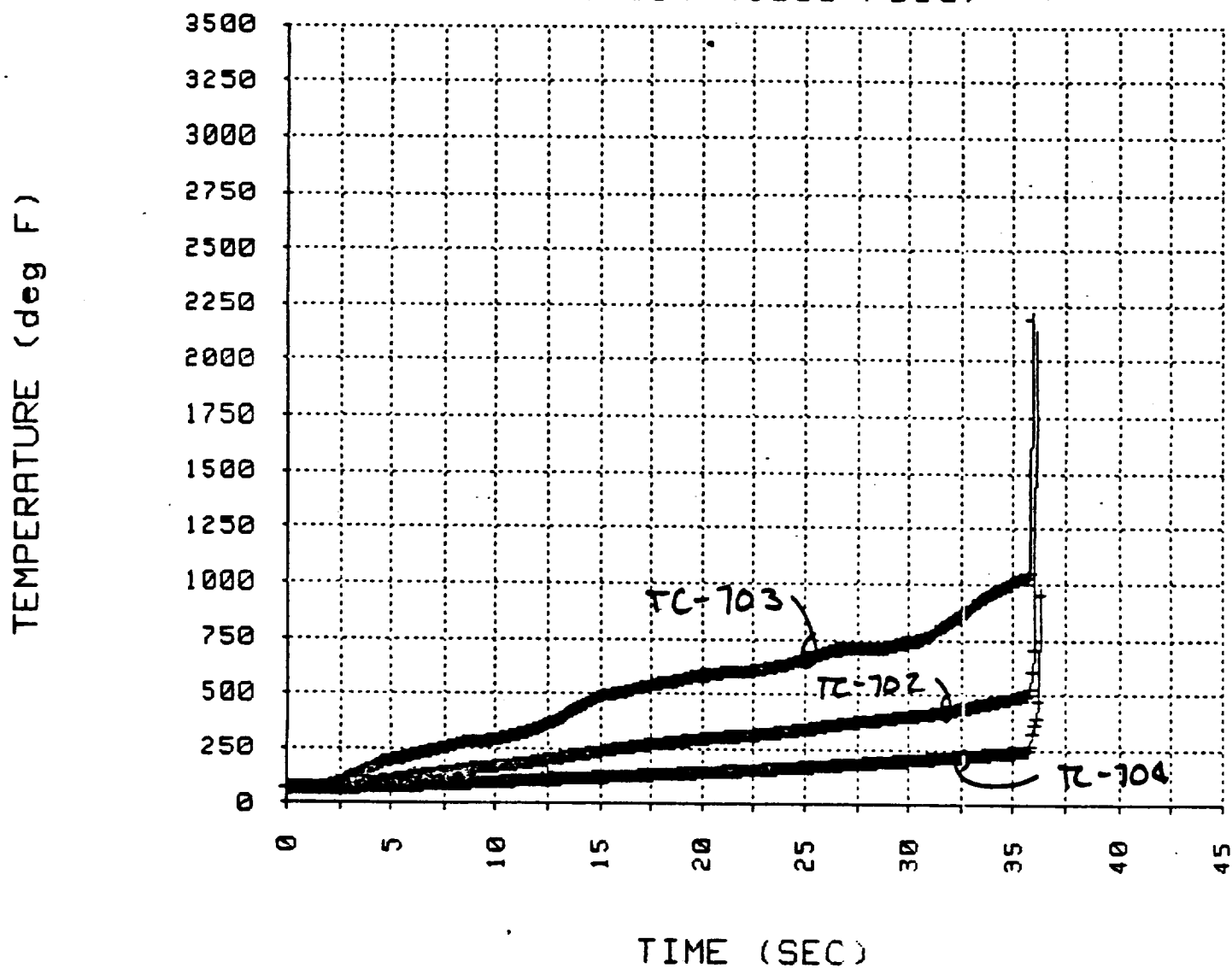


FRT #94 TEST #1 3/7/83

CHAMBER PRESSURE (PSIG)

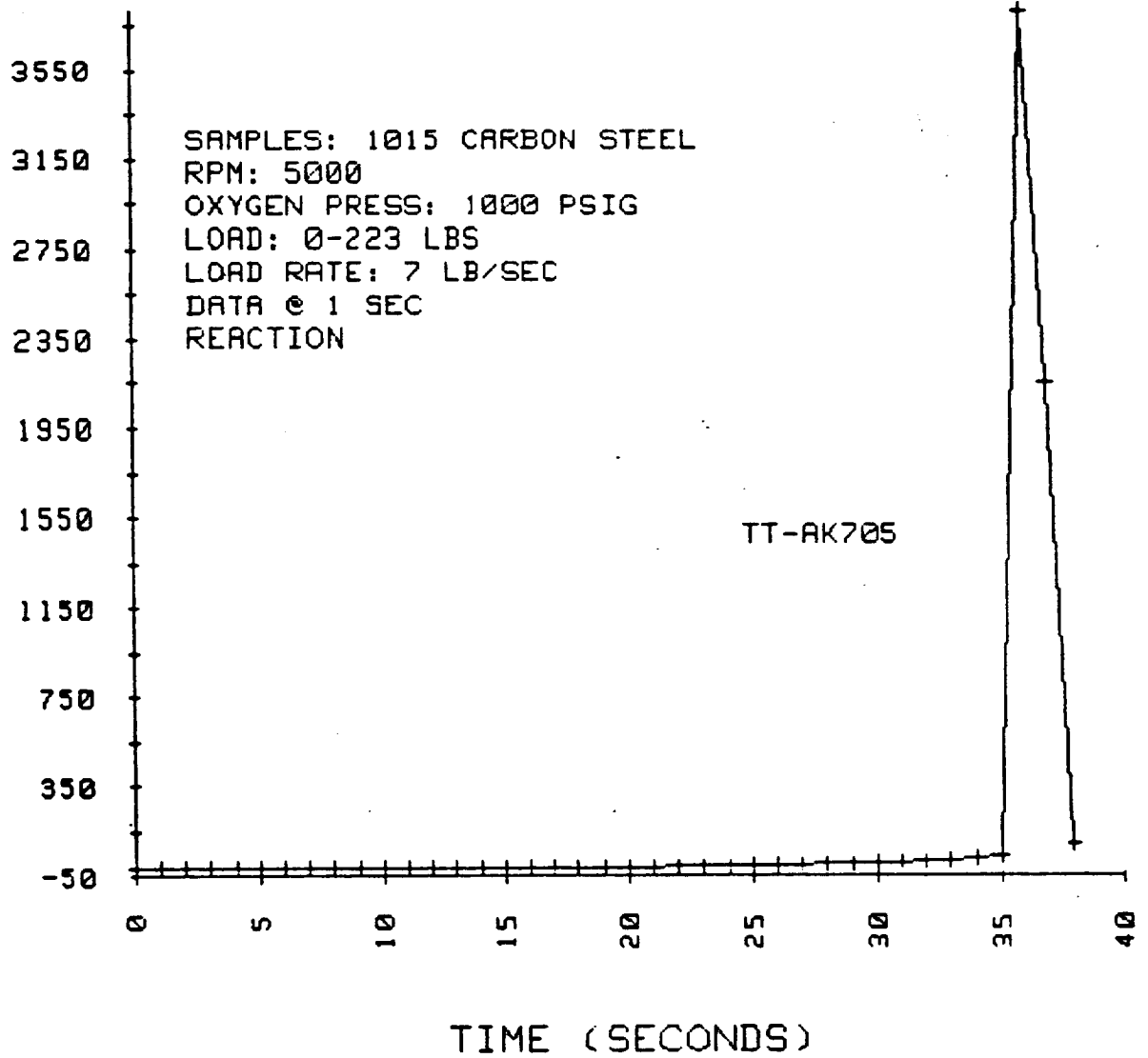


FRT #94 (1000 PSIG)



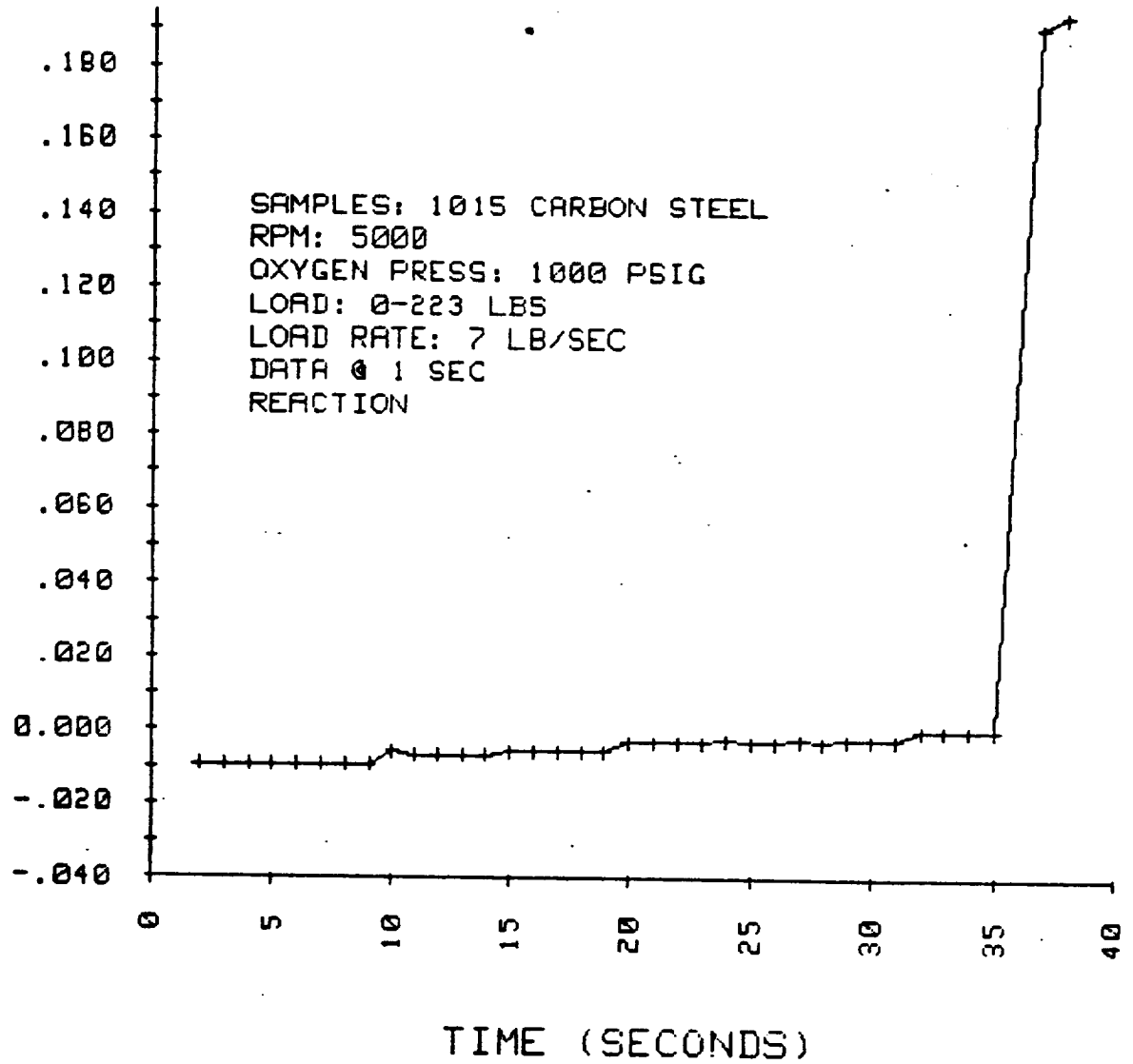
FRT #94 TEST #1 3/7/83

THERMOPILE OUTPUT (1/100MV)



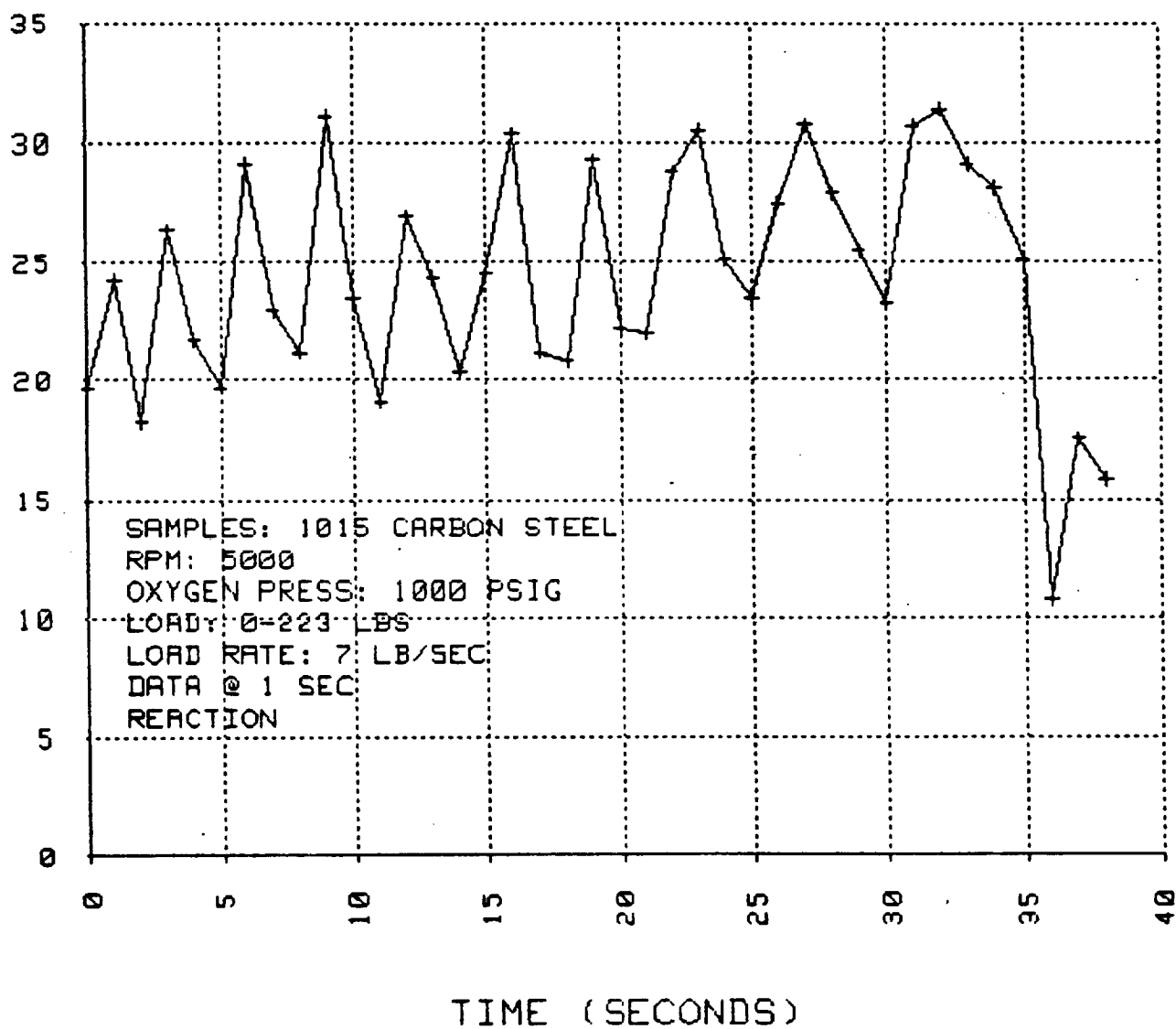
FRT #94 TEST #1 3/7/83

SAMPLE DISPLACEMENT (INCHES)

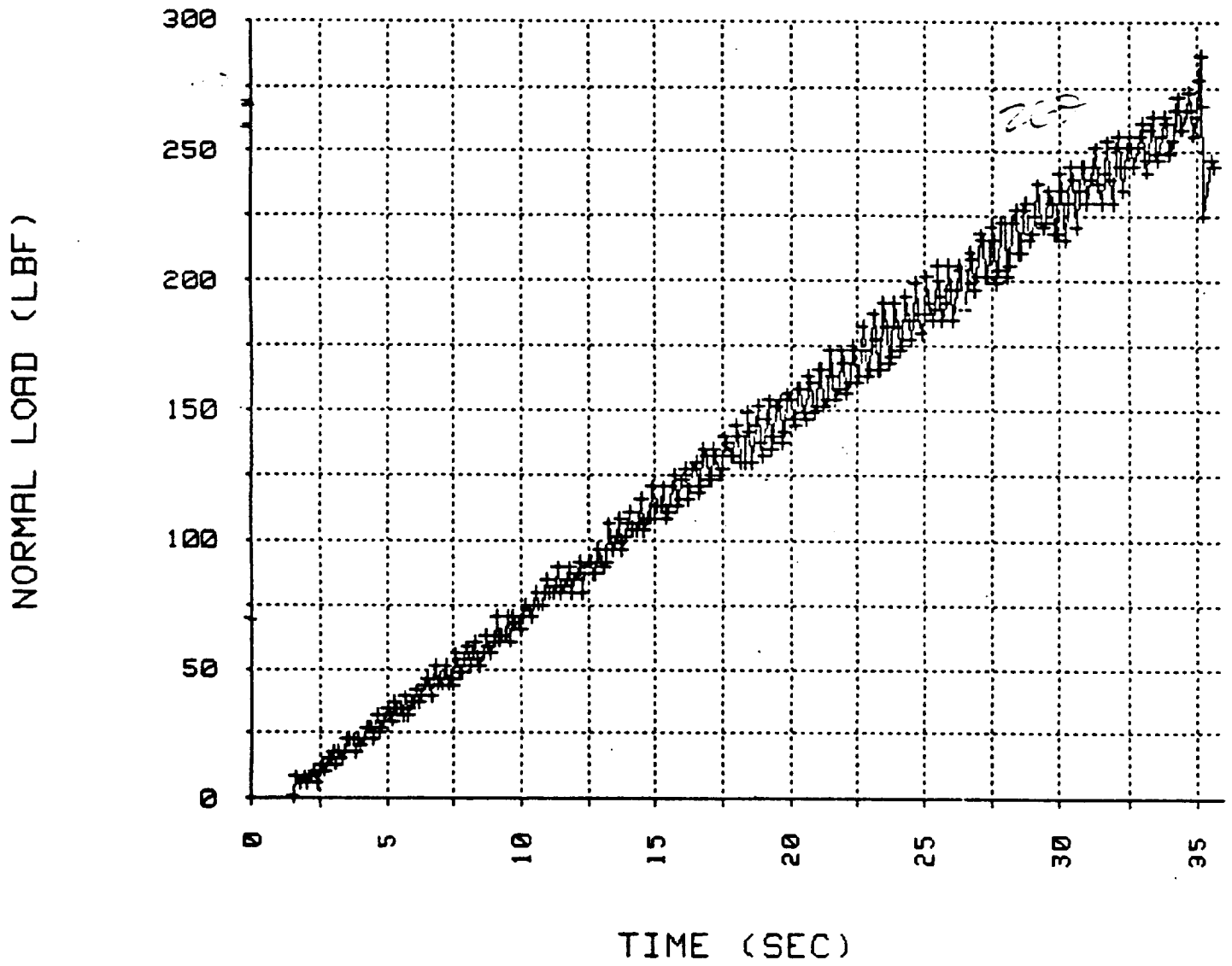


FRT #94 TEST #1 3/7/83

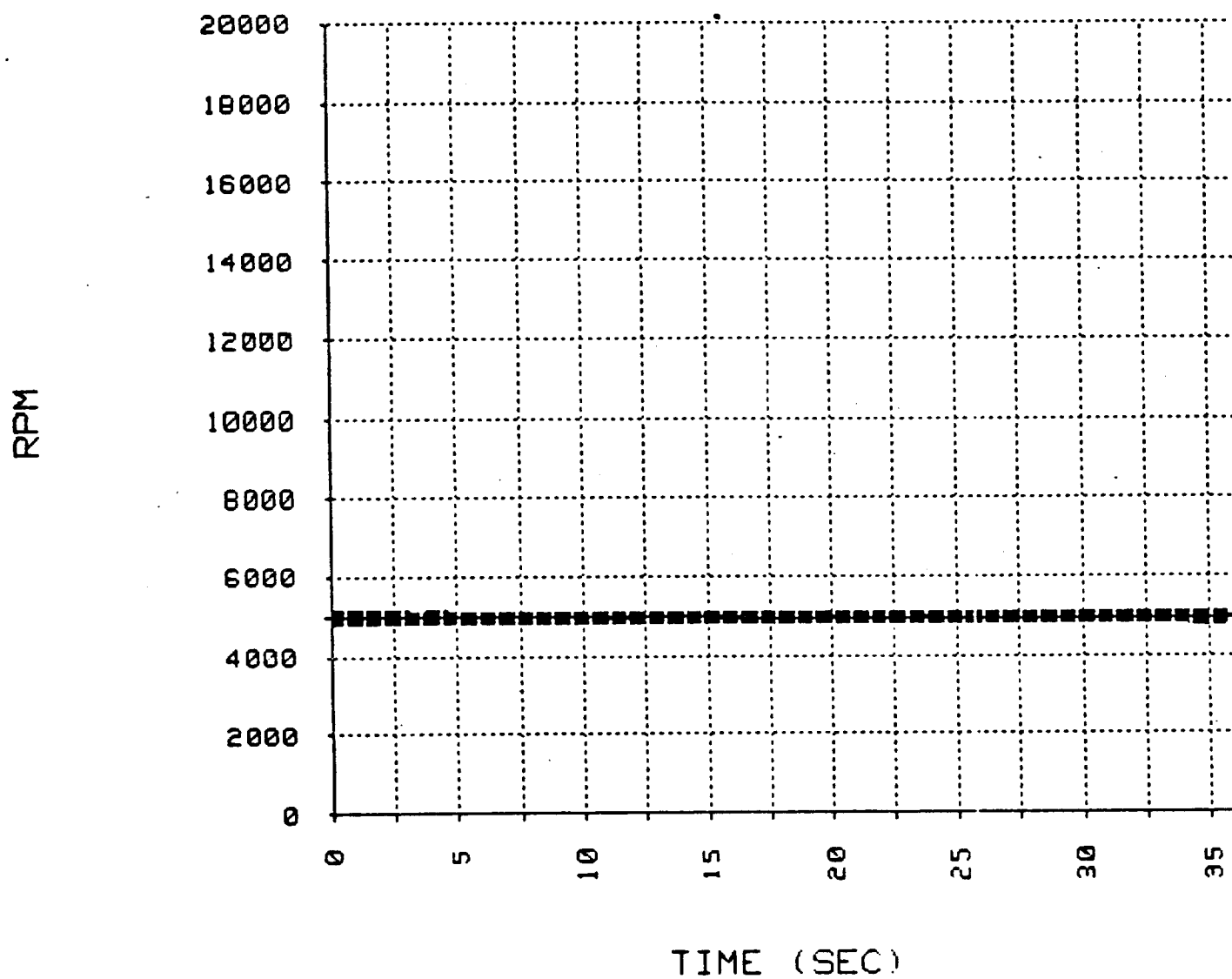
CHAMBER TORQUE LOAD (POUNDS)



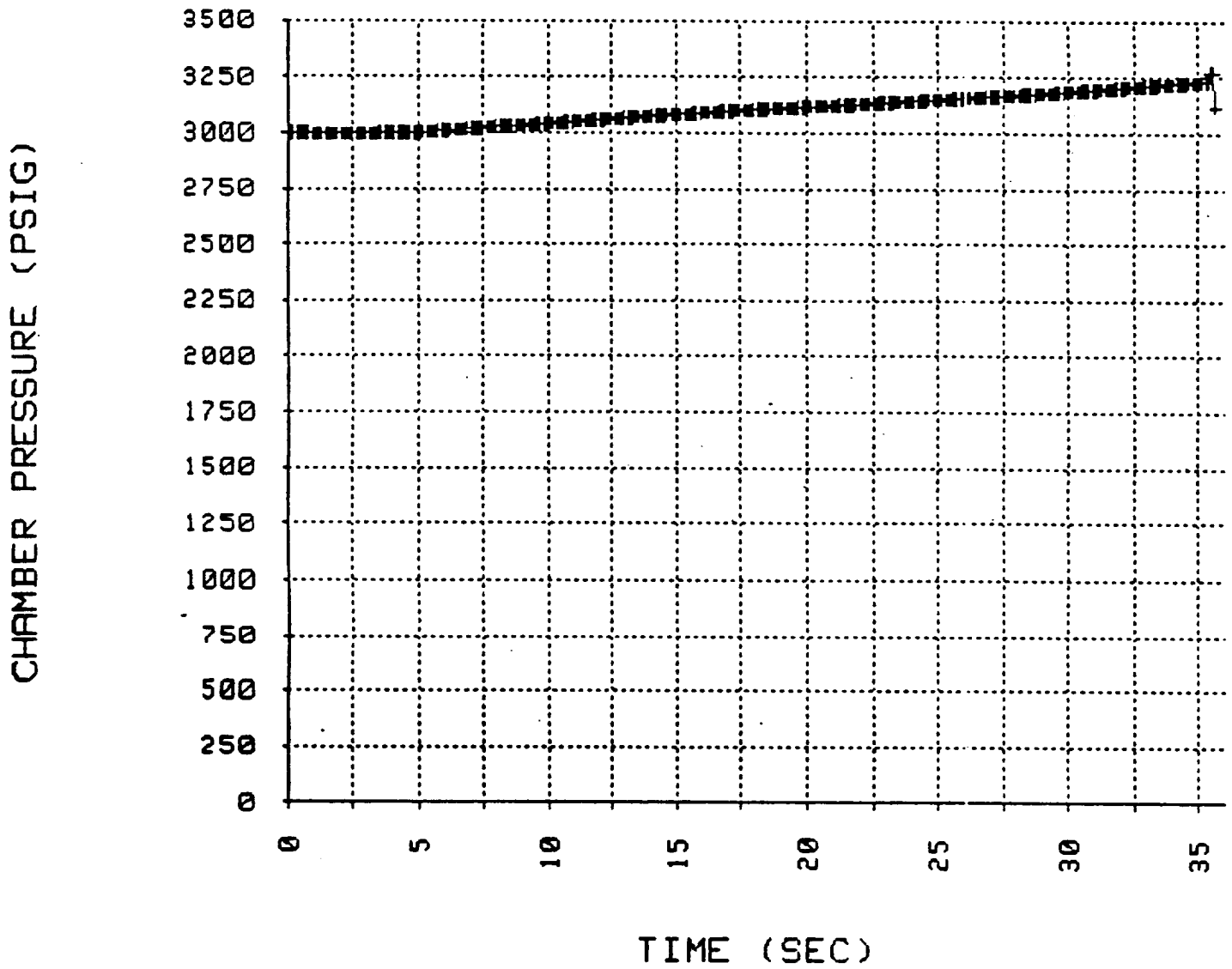
FRT #215



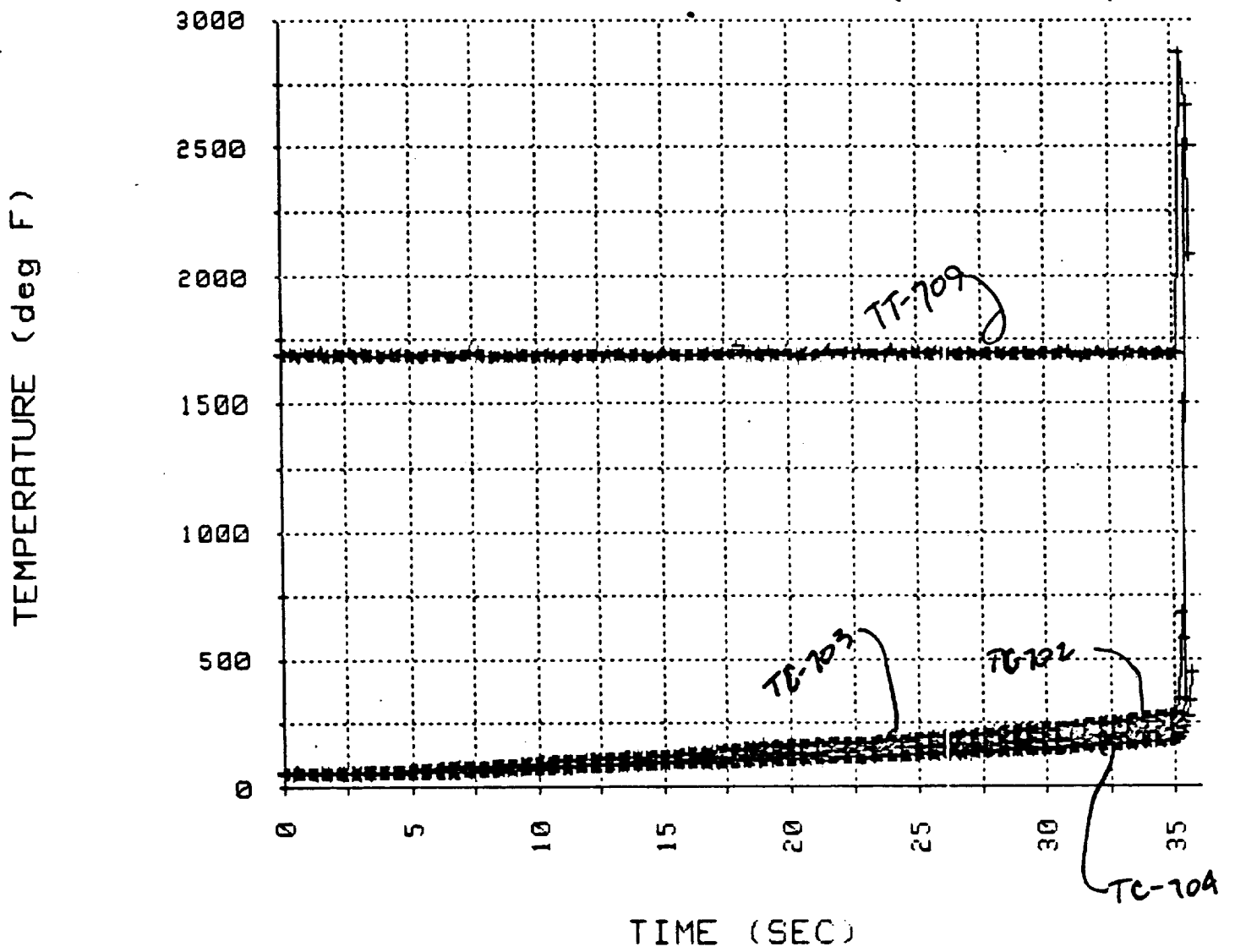
FRT #215



FRT #215

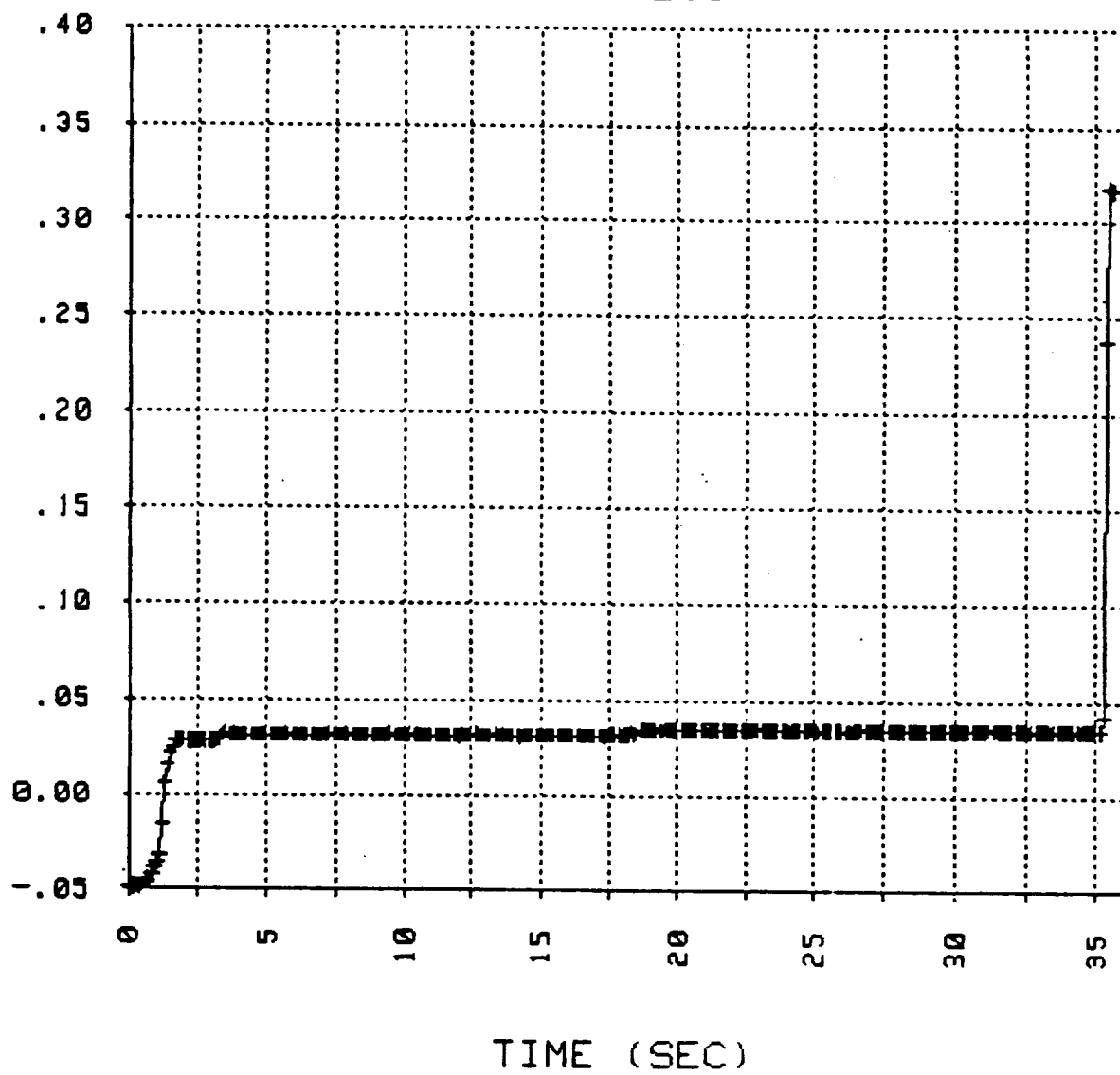


FRT #215 (3000 PSIG)

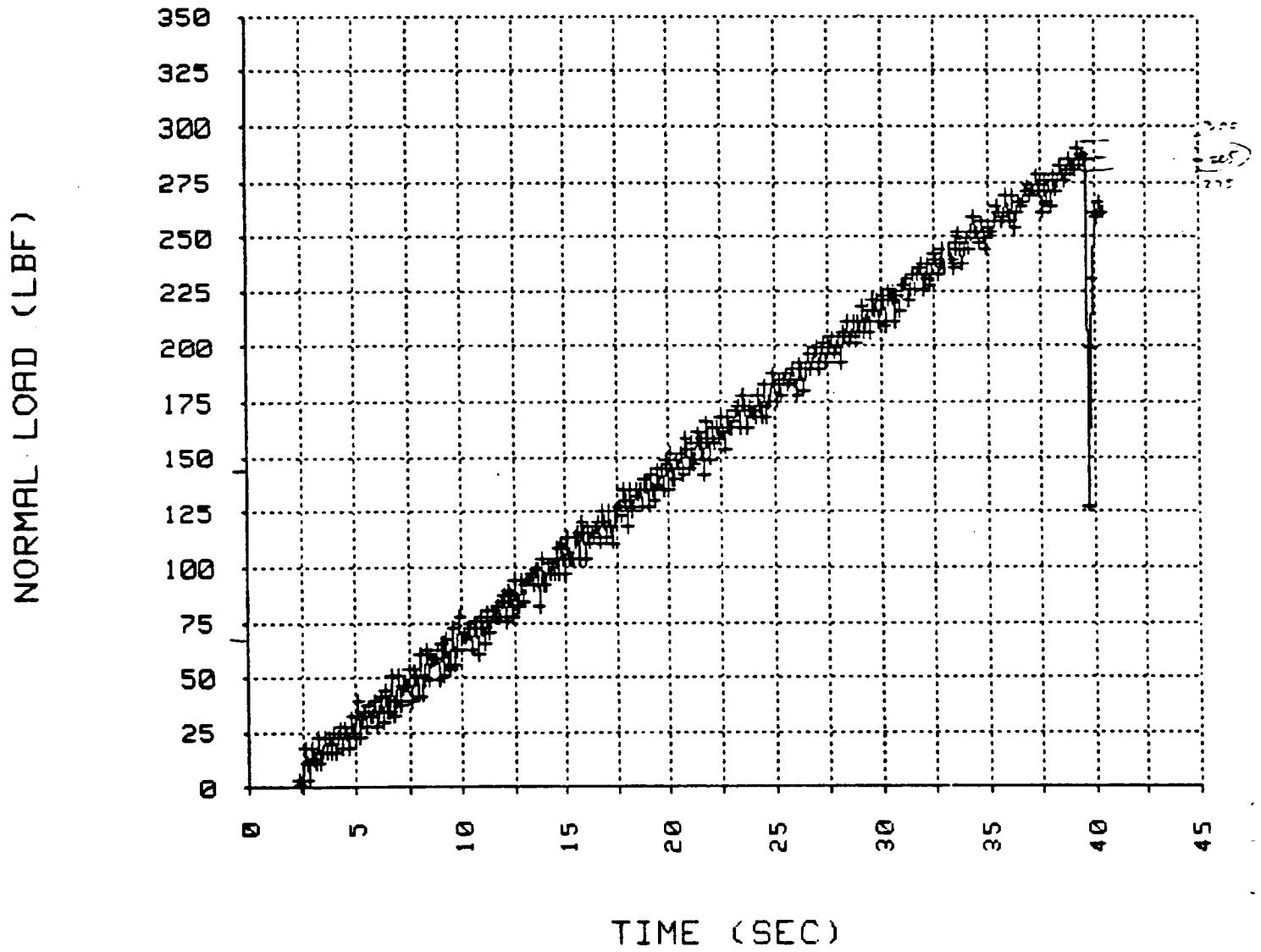


DISPLACEMENT (in)

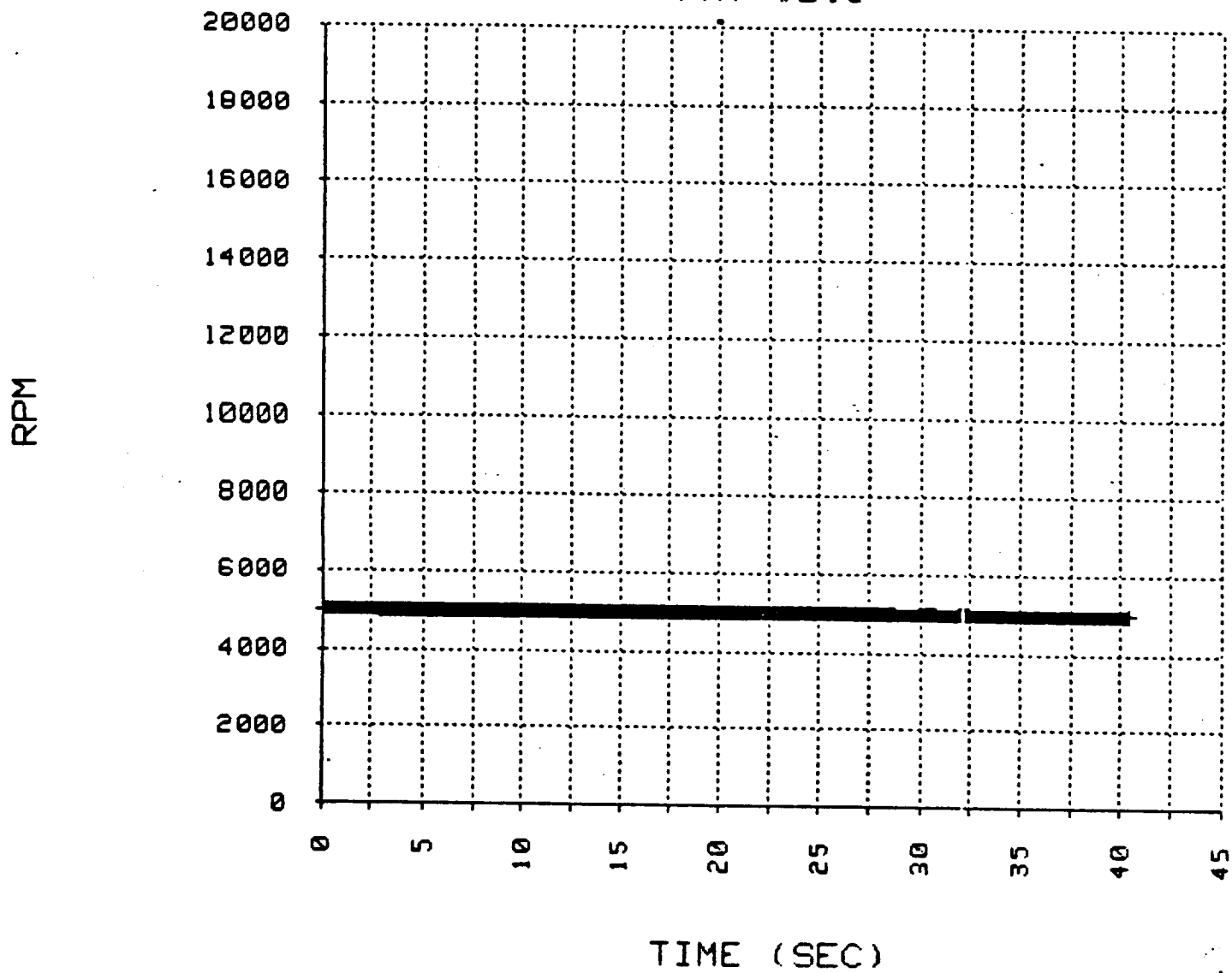
FRT #215



FRT #216

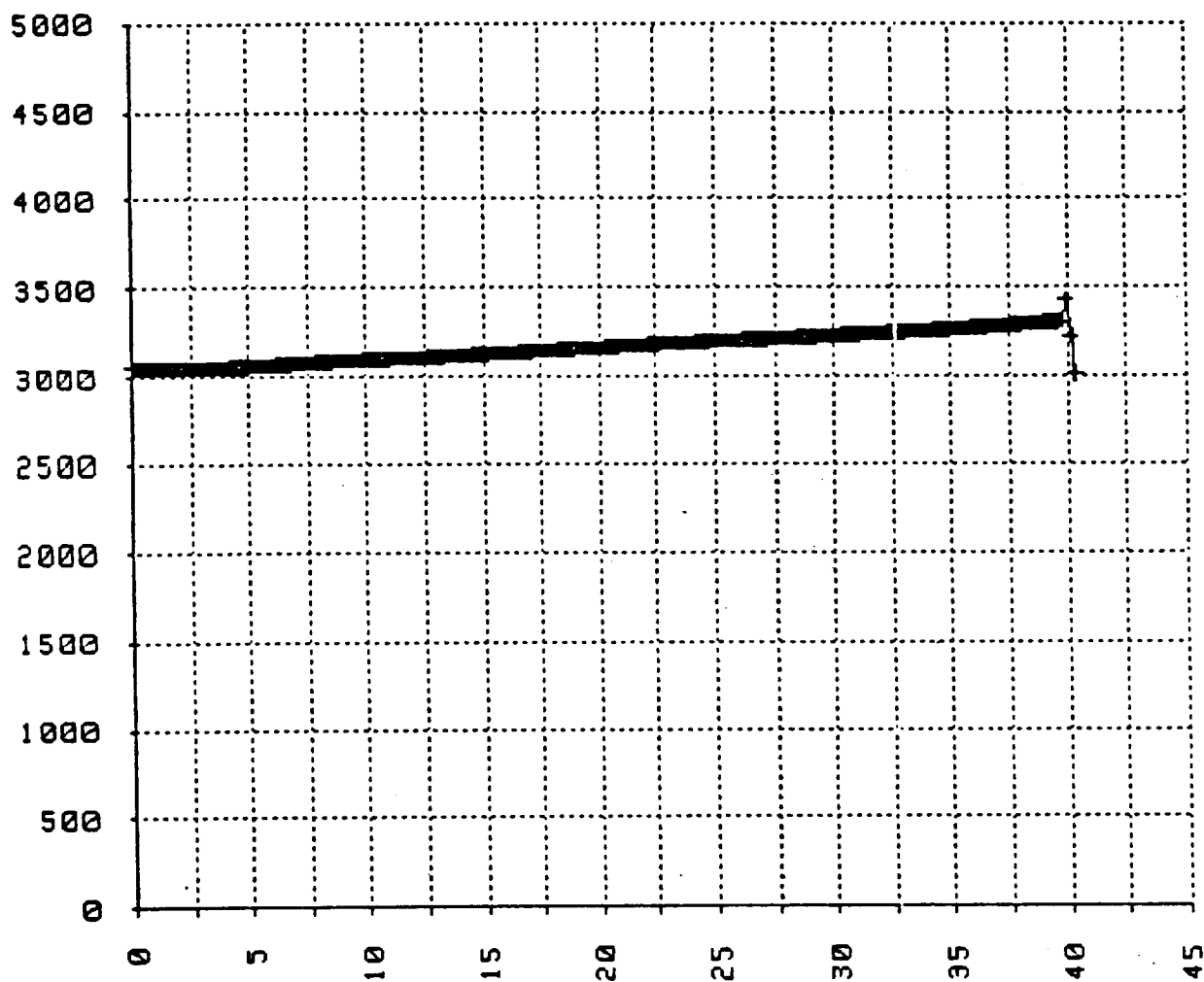


FRT #216



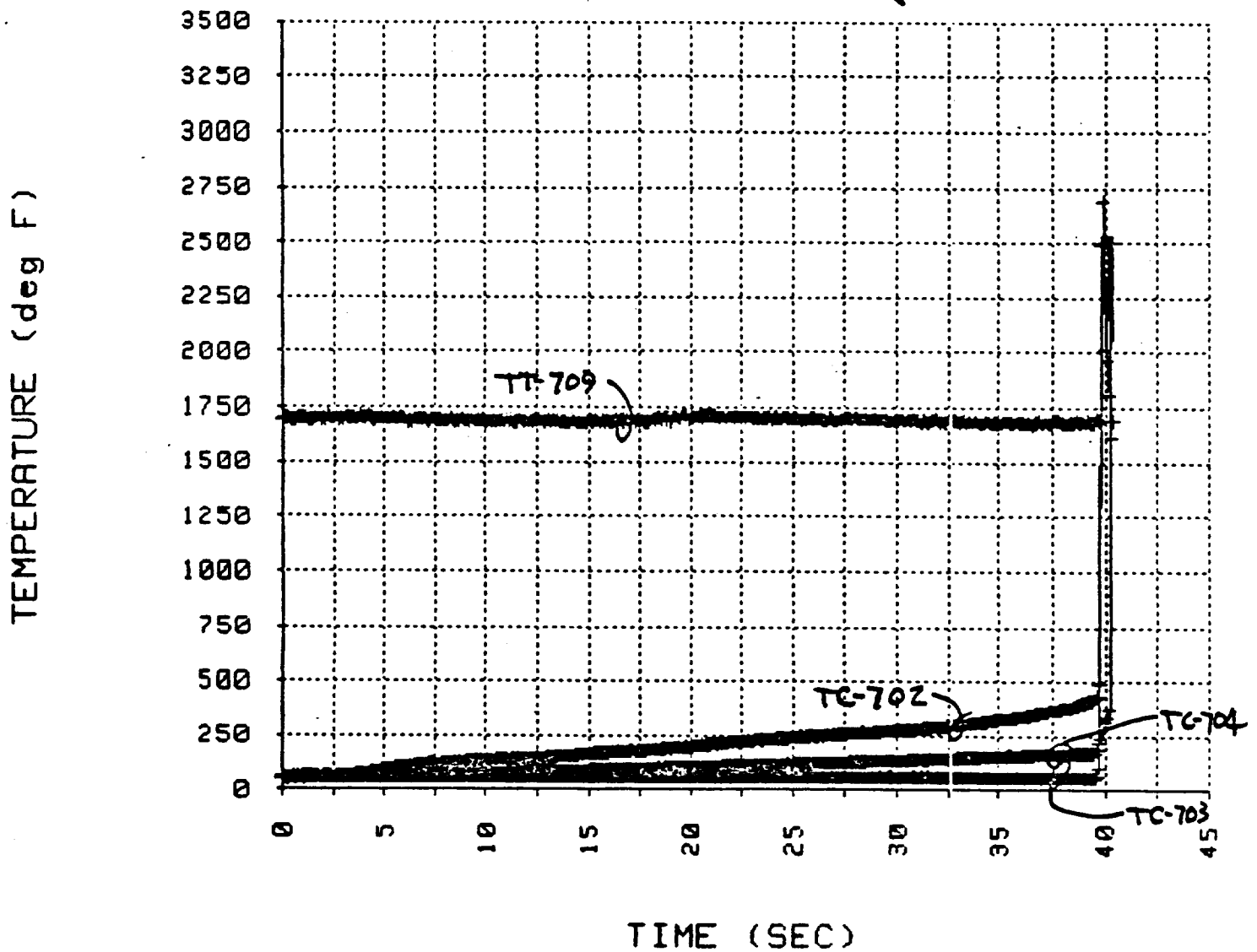
CHAMBER PRESSURE (PSIG)

FRT #216



TIME (SEC)

FRT #216 (3000 PSIG)



FRT #216

